REPAIR, EVALUATION, MAINTENANCE, AND REHABILITATION RESEARCH PROGRAM

TECHNICAL REPORT REMR-HY-7

LOCK ACCIDENT STUDY

by

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Final Report

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	Problem Area		Problem Area
CS	Concrete and Steel Structures	EM	Electrical and Mechanical
GT	Geotechnical	EI	Environmental Impacts
HY	Hydraulics	OM	Operations Management
CO	Coastal		

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COVER PHOTOS:

TOP — Upbound tow approaching old Gallipolis Lock structure on the Ohio River.

BOTTOM – Workers replace timbers on a miter gate damaged by vessel impact.

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FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Damages; Impact barrier; Lock accidents; Miter gates; Navigation

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Navigation locks were identified where extensive damages occur to the locks and the lock gates as a result of vessel collision. Data were collected from several sources in an attempt to quantify all damages resulting from accidents at locks including repair to the lock structure, losses due to delays, and damage to cargo and vessels. The study findings include the costs to repair 80 locks damaged by vessel impact. The statistics regarding repair costs in this report are based on data obtained from seven US Army Corps of Engineer District offices for the period from 1977 to 1987. The survey includes locks on the Upper Mississippi and Ohio Rivers and their navigable tributaries such as the Tennessee, Illinois, and Monongahela Rivers. Analyses of data bases to obtain quantitative delay and vessel damages were inconclusive. Keywords: Boat/ship accidents;

A barrier system for locks is shown in Appendix A. Lock volume data are listed in Appendix B. The computer program used to download records from a data base to a software
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damage assessment;

A

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19. ABSTRACT (Continued).

package is included in Appendix C. Charts of the relationship between daily variation in average wait times and process times and number of vessel arrivals per day are included in Appendix D.

PREFACE

The work described in this report was authorized by Headquarters, US Army Corps of Engineers (HQUSACE), as part of the Hydraulics Problem Area of the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program. The work was performed under Work Unit 32322, "Lock Gate Impact Barriers," for which Ms. Sandra K. Martin, Hydraulics Laboratory (HL), US Army Engineer Waterways Experiment Station (WES), and Dr. Martin E. Lipinski, Civil Engineering Department, Herff College of Engineering, Memphis State University, Memphis, TN, were Principal Investigators. Mr. Glenn Drummond (CECW-EH) was the REMR Technical Monitor for this work.

The REMR Directorate of Research and Development Coordinator in USACE was Mr. Jesse A. Pfeiffer, Jr. (CERD-C), and members of the REMR Overview Committee were Mr. James E. Crews (CECW-OM), Chairman, and Dr. Tony C. Liu (CECW-EG). The REMR Program Manager was Mr. William F. McCleese (CEWES-SC-A) and the Problem Area Leader was Mr. Glenn A. Pickering, Chief, Hydraulic Structures Division (HSD), HL.

The work was performed at the Locks and Conduits Branch (LCB), HSD; and this report was prepared by Ms. Martin and Dr. Lipinski under the general supervision of Messrs. Frank A. Herrmann, Jr., Chief, HL; Richard A. Sager, Assistant Chief, HL; Pickering; and John F. George, Chief, LCB. Dr. Lipinski collected the data and performed analyses while under temporary assignment to WES, arranged under the provisions of the Intergovernmental Personnel Act of 1970. This report was edited by Mrs. Marsha C. Gay, Information Technology Laboratory, WES.

COL Larry B. Fulton, EN, was the Commander and Director of WES during preparation of this report. Dr. Robert W. Whalin was the Technical Director.

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LOCK ACCIDENT STUDY

PART I: INTRODUCTION

Work Unit Background

1. The primary objective of Research, Evaluation, Maintenance, and Rehabilitation Work Unit 32322, entitled "Lock Gate Impact Barriers," was to develop an effective method of protecting miter gates from vessel impact. As the work unit name implies, the purpose of the research was to provide a structural alternative, or impact barrier, which would protect the miter gates from an oncoming tow by arresting its momentum before collision with the miter gates. As a secondary objective, an economic assessment of the damages resulting from accidents to lock gates was required to determine the benefit effectiveness that retrofit of an impact barrier would have on an existing lock.

2. The research was conducted in several phases including a literature search, a physical model study, a design phase, and an accident study. Numerous barrier designs were found as a result of the literature search and were, in general, found to be common to locks abroad (Martin 1988). The physical model study quantified the kinetic energy produced by a barge train in the restrictive geometry imposed by a lock chamber (Martin 1989). Information obtained from the literature search and the physical model study was incorporated in the design phase to develop a conceptual barrier system specifically sized for retrofit on Lock and Dam 24 on the Mississippi River (Martin and Holmes 1989). This barrier design is shown in Appendix A. The economic assessment of damages, as mentioned previously, was addressed by means of this accident study.

Accident Study

Problem

3. Accidents in which vessels collide with lock structures occur frequently. These accidents can result in extensive repairs to both the lock and/or the vessel and in long delays while awaiting repairs. Another product of lock accidents not addressed by this study is the potential for injury

and/or loss of life. Determination of the causes and quantification of the effects (i.e., damages) begin the process of identifying solutions to the problem which potentially result in great economic returns.

4. Accidents are caused by sundry reasons which can occur in combination or alone. The primary causes of accidents are directly related but not limited to the following:

a. Excessive speed or inability to stop

b. Misalignment of the tow

c. Faulty communications between the lockmaster and tow operator

d. Equipment failure on the tow or the lock

e. Pilot error or poor judgment

f. Surges in the lock chamber due to filling system

g. Improperly secured mooring lines

h. Improper loading or lashing of barges

Indirect factors that affect safe maneuvering into the lock are river stage and discharge, current patterns, direction of travel, horsepower of the vessel, and visibility during approach. The combination of factors, direct or indirect, that cause tows to collide with lock gates is at the very least a complex phenomenon (US Army Engineer Division, Ohio River, 1981).

Need

5. The accident study was conducted to identify the need to reduce accidents, regardless of cause, by quantifying the damages associated with accidents. This study provided information on navigation accidents at selected US Army Corps of Engineers (USACE) District Offices and identified the locks in those Districts with high accident rates and large repair costs.

Objectives and Scope

6. The objectives of this investigation were to evaluate the costs associated with navigation accidents involving collisions with lock gates and to develop a risk assessment methodology that could provide the basis for conducting cost-effective evaluations of potential structural solutions. The accident cost analysis was conducted in two phases, the first focusing on direct costs of accidents as measured by damage estimates, and the second consisting of estimates of the economic impact of delays resulting from accidents that caused interruptions in lock service.

PART II: COLLECTION OF THE DATA

7. A review of existing data bases was conducted to determine the availability of information relating to accident costs. The following four potential data sources were reviewed:

a. The Safety Information Management System (SIMS), a data base maintained by the USACE Safety Office (SIMS, no date).

b. The Casualty Maintenance (CASMAIN) accident records system maintained by the US Coast Guard (CASMAIN, no date).

c. The Performance Monitoring System (PMS) containing information for all lockages at facilities maintained by the USACE (Fleming, Wood, and Goodwin 1985).

d. Records kept by each USACE District Office on accidents involving damage to US Government property for collisions at locks and dams within the individual jurisdictions.

SIMS

8. The SIMS contains information relating to accidents for all USACE facilities. All accidents are presumably reported on Eng Form 3394, "Accident Investigation Report" (Figure 1), and pertinent data items then transferred to the data base.* One of the data elements identifying the accident type falls under the category of navigation accidents. A microcomputer-based set of the SIMS data for the period 1984-1986 was obtained and a listing of all navigation-related accidents in the system was prepared.

9. A pilot study was undertaken comparing the information in the SIMS data base on lock accidents in the St. Louis District with the records maintained by the District. (The District conducts investigations of all accidents that result in damage to Government property for the purpose of developing cost estimates for the necessary repair work. These estimates, developed by Corps personnel, are used to collect damages from the companies whose vessels are involved in the accidents.) This comparison revealed significant discrepancies between the two data sets. While all the navigation accidents in the SIMS data were also listed in the District records, a significant number of incidents in the District files did not appear in the SIMS data base.

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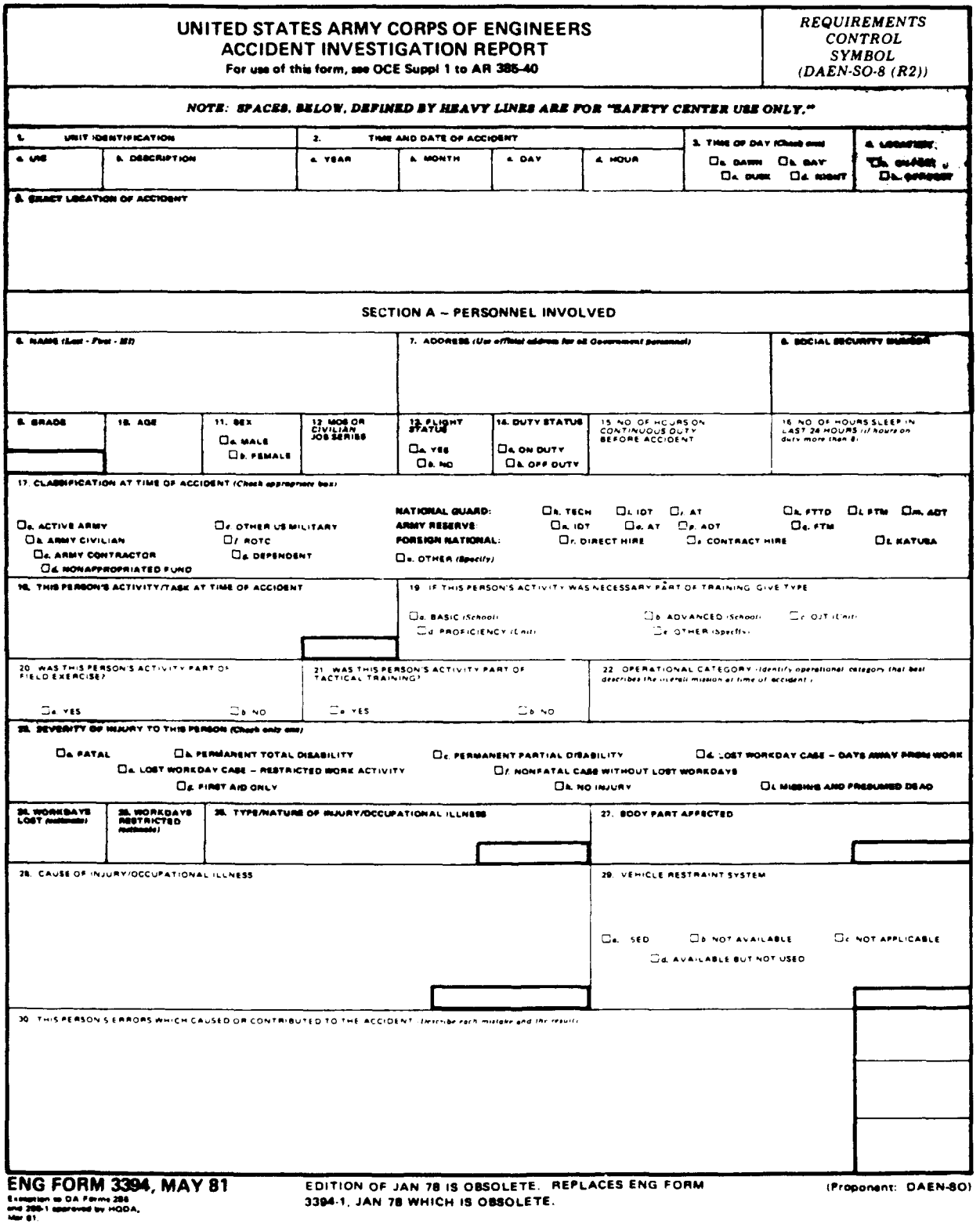
* This form is now obsolete and has been replaced with a more current version dated September 1989.



UNITED STATES ARMY CORPS OF ENGINEERS
ACCIDENT INVESTIGATION REPORT
For use of this form, see OCE Suppl 1 to AR 385-40

REQUIREMENTS CONTROL SYMBOL (DAEN-SO-8 (R2))

NOTE: SPACES, BELOW, DEFINED BY HEAVY LINES ARE FOR "SAFETY CENTER USE ONLY."

1. UNIT IDENTIFICATION — a. UIC; b. DESCRIPTION
2. TIME AND DATE OF ACCIDENT — a. YEAR; b. MONTH; c. DAY; d. HOUR
3. TIME OF DAY (Check one) — ☐a. DAWN ☐b. DAY ☐c. DUSK ☐d. NIGHT
4. LOCATION: ☐a. ON POST ☐b. OFF POST
5. EXACT LOCATION OF ACCIDENT

SECTION A – PERSONNEL INVOLVED

6. NAME (Last - First - MI)
7. ADDRESS (Use official address for all Government personnel)
8. SOCIAL SECURITY NUMBER
9. GRADE
10. AGE
11. SEX — ☐a. MALE ☐b. FEMALE
12. MOS OR CIVILIAN JOB SERIES
13. FLIGHT STATUS — ☐a. YES ☐b. NO
14. DUTY STATUS — ☐a. ON DUTY ☐b. OFF DUTY
15. NO. OF HOURS ON CONTINUOUS DUTY BEFORE ACCIDENT
16. NO. OF HOURS SLEEP IN LAST 24 HOURS (If hours on duty more than 8)
17. CLASSIFICATION AT TIME OF ACCIDENT (Check appropriate box)
☐a. ACTIVE ARMY ☐b. ARMY CIVILIAN ☐c. ARMY CONTRACTOR ☐d. NONAPPROPRIATED FUND ☐e. OTHER US MILITARY ☐f. ROTC ☐g. DEPENDENT
NATIONAL GUARD: ☐a. TECH ☐b. IDT ☐c. AT ☐d. ADT ☐e. FTTD ☐f. FTM ☐m. ADT
ARMY RESERVE: ☐a. IDT ☐e. AT ☐f. ADT ☐g. FTM
FOREIGN NATIONAL: ☐f. DIRECT HIRE ☐g. CONTRACT HIRE ☐h. OTHER (Specify) ☐i. KATUSA
18. THIS PERSON'S ACTIVITY/TASK AT TIME OF ACCIDENT
19. IF THIS PERSON'S ACTIVITY WAS NECESSARY PART OF TRAINING GIVE TYPE
☐a. BASIC (School) ☐b. ADVANCED (School) ☐c. OJT (Unit) ☐d. PROFICIENCY (Unit) ☐e. OTHER (Specify)
20. WAS THIS PERSON'S ACTIVITY PART OF FIELD EXERCISE? ☐a. YES ☐b. NO
21. WAS THIS PERSON'S ACTIVITY PART OF TACTICAL TRAINING? ☐a. YES ☐b. NO
22. OPERATIONAL CATEGORY (Identify operational category that best describes the overall mission at time of accident.)
23. SEVERITY OF INJURY TO THIS PERSON (Check only one)
☐a. FATAL ☐b. PERMANENT TOTAL DISABILITY ☐c. PERMANENT PARTIAL DISABILITY ☐d. LOST WORKDAY CASE – DAYS AWAY FROM WORK ☐e. LOST WORKDAY CASE – RESTRICTED WORK ACTIVITY ☐f. NONFATAL CASE WITHOUT LOST WORKDAYS ☐g. FIRST AID ONLY ☐h. NO INJURY ☐i. MISSING AND PRESUMED DEAD
24. WORKDAYS LOST (Estimate)
25. WORKDAYS RESTRICTED (Estimate)
26. TYPE/NATURE OF INJURY/OCCUPATIONAL ILLNESS
27. BODY PART AFFECTED
28. CAUSE OF INJURY/OCCUPATIONAL ILLNESS
29. VEHICLE RESTRAINT SYSTEM
☐a. SED ☐b. NOT AVAILABLE ☐c. NOT APPLICABLE ☐d. AVAILABLE BUT NOT USED
30. THIS PERSON'S ERRORS WHICH CAUSED OR CONTRIBUTED TO THE ACCIDENT (Describe each mistake and the result)

ENG FORM 3394, MAY 81
Exception to DA Forms 285 and 285-1 approved by HQDA, Mar 81.

EDITION OF JAN 78 IS OBSOLETE. REPLACES ENG FORM 3394-1, JAN 78 WHICH IS OBSOLETE.

(Proponent: DAEN-SO)

Figure 1. SIMS data form (Sheet 1 of 4)

SECTION B – PROPERTY AND/OR MATERIEL INVOLVED

31. LIST ALL PROPERTY INVOLVED IN THE ACCIDENT WHETHER DAMAGED OR NOT. IF ACCIDENT INVOLVED ARMY OPERATIONS, SHOW COST OF ANY DAMAGE.

NO	a NAME OF ITEM (Complete nomenclature (e.g., name, type, model))		b OWNERSHIP		c AMOUNT OF DAMAGE
1					
2					
3					

32. MATERIEL FAILURE(S)/MALFUNCTION(S) WHICH CAUSED OR CONTRIBUTED TO THE ACCIDENT (Tell what failed and how it failed.)

33. CONTROL NUMBER FOR THE E.R. COVERING EACH FAILURE/MALFUNCTION (Block 1 of SF 368)

SECTION C – ENVIRONMENTAL CONDITIONS INVOLVED

34. ENVIRONMENTAL CONDITION(S) WHICH CAUSED OR CONTRIBUTED TO THE ACCIDENT

SECTION D – DESCRIPTION AND CORRECTIVE ACTION

35. FULLY DESCRIBE THE ACCIDENT. (How material listed in Item 31 failed, how involved personnel are related to it.)

36. ACTION TAKEN, ANTICIPATED, OR RECOMMENDED TO CORRECT THE CAUSE(S) OF THIS ACCIDENT

37. SIGNATURE OF COMMAND REPRESENTATIVE	38. COMMAND REVIEW		
	a.	b.	c.

SAFETY STAFF USE ONLY

39. REPORT SUBMISSION	40. MACOM	41. LOCAL REPORT NUMBER	42. ACCIDENT TYPE	43. TYPE OF VEHICLE COLLISION
☐a. INITIAL ☐b. CHANGE				

44. SAFETY STAFF POINT OF CONTACT (Include printed name and phone)	45. SPECIAL REQUIREMENTS	46. DATE REPORT COMPLETED (Yr Mo Day)

PAGE 2 OF 4 PAGES

Figure 1. (Sheet 2 of 4)

SECTION E – SUPPLEMENTAL DATA

47. TRAINING COMPLETED *(Government personnel only)*

48. PHASE OF CONSTRUCTION *(Construction activities only)*

1. ☐ MOBILIZATION	8. ☐ STEEL ERECTION	15. ☐ UTILITIES
2. ☐ SITE PREPARATION	9. ☐ SCAFFOLDING	16. ☐ MECHANICAL
3. ☐ EXCAVATION AND EARTHWORK	10. ☐ ROOFING	17. ☐ TUNNELING
4. ☐ FOUNDATION	11. ☐ CARPENTRY, EXTERIOR	18. ☐ DEMOLITION
5. ☐ FORMING	12. ☐ CARPENTRY, INTERIOR	19. ☐ WAREHOUSING
6. ☐ FRAMING	13. ☐ TRIM EXTERIOR	20. ☐ OTHER
7. ☐ CONCRETE PLACEMENT	14. ☐ TRIM, INTERIOR	

49. SAFETY REQUIREMENT VIOLATED *(See EM 385-1-1)*

SECTION F - NAVIGATION MISHAPS

50. COAST GUARD LICENSE

1. ☐ YES 2. ☐ NO

51. NUMBER OF BARGES

LOADED ☐☐ LIGHT ☐☐

52. H.P. OF TOW

1. ☐ UP TO 1000
2. ☐ 1001-3000
3. ☐ 3001-5000
4. ☐ 5001-7500
5. ☐ 7501 AND UP

53. GROSS TONNAGE OF TOW

1. ☐ UP TO 6000 TONS
2. ☐ 6001-9000 TONS
3. ☐ 9001-12000 TONS
4. ☐ 12001-15000 TONS
5. ☐ 15001 AND OVER

54. COLLISION MISHAP

1. COLLISION W/OTHER VESSEL
2. UPPER GUIDE WALL
3. UPPER LOCK GATES
4. LOCK WALL
5. LOWER LOCK GATES
6. LOWER GUIDE WALL
7. TOW BREAK UP
8. SWEPT DOWN ON DAM
9. BUOY OR DOLPHIN
10. WHARVES & DOCKS
11. OTHER

PRIMARY ☐☐ SECONDARY ☐☐

55. NAVIGATION AIDS

1. ☐ SUPERVISED
2. ☐ NOT SUPERVISED

56. APPROACH

DOWN RIVER	UP RIVER
1. ☐ WAY ON	3. ☐ WAY ON
2. ☐ WAITING	4. ☐ WAITING

SECTION G - CORPS OF ENGINEERS SPECIAL REQUIREMENTS

57. OFFICE ASSIGNED *(Government personnel only)*

DIVISION BRANCH

58. RECORDABILITY

DA ACCOUNTABLE
☐ YES
☐ NO

CE INTEREST ONLY *(Not included in FOA statistical data)*
☐ YES
☐ NO

Figure 1. (Sheet 3 of 4)

SECTION H – DETAILED ACCIDENT ANALYSIS

59. LOCAL REPORT NUMBER	60. TIME AND DATE OF ACCIDENT				61. UNIT UIC
	a. YEAR	b. MONTH	c. DAY	d. HOUR	
62. TELL WHAT HAPPENED	63. TELL WHAT CAUSED ALLOWED IT TO HAPPEN				64. TELL WHAT TO DO ABOUT IT

U.S. GOVERNMENT PRINTING OFFICE : 1982 O - 389-230

PAGE 4 of 4 PAGES

Figure 1. (Sheet 4 of 4)

10. Based on the results of this pilot study, it was concluded that the SIMS data base could not be used in this investigation because it did not contain a complete listing of all accident events.

CASMAIN

11. The CASMAIN system is maintained by the US Coast Guard and contains information on commercial marine accidents occurring in US waters or involving US flagged vessels. Accidents on the inland waterways system are reported to the US Coast Guard on Form CG-2692, "Report of Marine Accident, Injury or Death" (Figure 2) and then transferred into the data base. CASMAIN records include estimates of vessel damage but do not indicate damage to other property such as lock structures. Since information regarding vessel damage is a part of the total direct cost of an accident, the CASMAIN system was reviewed to determine if it could provide data to supplement other damage estimates.

12. Another pilot study, similar to the one performed with SIMS, was undertaken to determine if there were CASMAIN entries corresponding to the accidents cataloged at the District level. The results of this comparison were disappointing as only a limited number of the accidents were found in the CASMAIN system. Therefore, the CASMAIN system was rejected as a source of vessel damage information for this study.

13. Alternative sources for vessel damage information such as records maintained by the individual towboat companies and insurance records were investigated. Due to the confidential nature of the data and difficulties in identifying vessel damage costs with individual incidents, vessel damages were not obtained at this time.

14. Further investigations, however, should attempt to obtain these data concerning vessel and cargo damages from towboat companies or marine insurance agencies. Because of the privileged nature of this information, aggregated data will have to be analyzed instead of accident-specific information.

PMS

15. The PMS is a part of the Inland Navigation Systems Analysis (INSA) program and includes data collected since 1975 at all Corps-owned and -operated locks. The data consist of information describing the traffic

DEPARTMENT OF TRANSPORTATION
U. S. COAST GUARD
CG-2692 (Rev. 6-87)

REPORT OF MARINE ACCIDENT, INJURY OR DEATH

RCS No. G-MMI 2115-003

UNIT CASE NUMBER

SECTION I. GENERAL INFORMATION

1. Name of Vessel or Facility	2. Official No.	3. Nationality	4. Call Sign	5. USCG Certificate of Inspection issued at

6. Type (Towing, Freight, Fish, Drill, etc.)	7. Length	8. Gross Tons	9. Year Built	10. Propulsion (Steam, diesel, gas, turbine...)

11. Hull Material (Steel, Wood...)	12. Draft (ft. - in.) FWD	AFT	13. If Vessel Classed, By Whom: (ABS, LLOYDS, DNV, BV, etc.)	14. Date (of occurrence)	15. TIME (Local)

16. Location (See Instruction No. 10A)	17. Estimated Loss or Damage TO:
	VESSEL $ _____
18. Name, Address & Telephone No. of Operating Co.	CARGO $ _____
	OTHER $ _____

19. Name of Master or Person in Charge	USCG License ☐ YES ☐ NO	20. Name of Pilot	USCG License ☐ YES ☐ NO	State License ☐ YES ☐ NO

19a. Street Address (City, State, Zip Code)	19b. Telephone Number ( )	20a. Street Address (City, State, Zip Code)	20b. Telephone Number ( )

21. Casualty Elements (Check as many as needed and explain in Block 44.)

- NO. OF PERSONS ON BOARD _____
- ☐ DEATH- HOW MANY? _____
- ☐ MISSING- HOW MANY? _____
- ☐ INJURED- HOW MANY? _____
- ☐ HAZARDOUS MATERIAL RELEASED OR INVOLVED (Identify Substance and amount in Block 44.)
- ☐ OIL SPILL-ESTIMATE AMOUNT: _____
- ☐ CARGO CONTAINER LOST/DAMAGED
- ☐ COLLISON (Identify other vessel or object in Block 44.)
- ☐ GROUNDING ☐ WAKE DAMAGE
- ☐ FLOODING; SWAMPING WITHOUT SINKING
- ☐ CAPSIZING (with or without sinking)
- ☐ FOUNDERING OR SINKING
- ☐ HEAVY WEATHER DAMAGE
- ☐ FIRE
- ☐ EXPLOSION
- ☐ COMMERCIAL DIVING CASUALTY
- ☐ ICE DAMAGE
- ☐ DAMAGE TO AIDS TO NAVIGATION
- ☐ STEERING FAILURE
- ☐ MACHINERY OR EQUIPMENT FAILURE
- ☐ ELECTRICAL FAILURE
- ☐ STRUCTURAL FAILURE
- ☐ FIREFIGHTING OR EMERGENCY EQUIPMENT FAILED OR INADEQUATE (Describe in Block 44.)
- ☐ LIFESAVING EQUIPMENT FAILED OR INADEQUATE (Describe in Block 44.)
- ☐ BLOW OUT (Petroleum exploration/production)
- ☐ ALCOHOL INVOLVEMENT (Describe in Block 44.)
- ☐ DRUG INVOLVEMENT (Describe in Block 44.)
- ☐ OTHER (Specify) _____

22. Conditions

A. Sea or River Conditions (wave height, river stage, etc.)	B. WEATHER	C. TIME	D. VISIBILITY
	☐ CLEAR	☐ DAYLIGHT	☐ GOOD
	☐ RAIN	☐ TWILIGHT	☐ FAIR
	☐ SNOW	☐ NIGHT	☐ POOR
	☐ FOG		
	☐ OTHER (Specify) _____		

E. DISTANCE (miles) _____ (of visibility)
F. AIR TEMPERATURE _____ (F)
G. WIND SPEED & DIRECTION _____ _____
H. CURRENT SPEED & DIRECTION _____ _____

23. Navigation Information		24. Last Port Where Bound	24a. Time and Date of Departure
☐ MOORED, DOCKED OR FIXED ☐ ANCHORED ☐ UNDERWAY OR DRIFTING	SPEED AND COURSE _____	_____	

25. FOR TOWING ONLY	25a. NUMBER OF VESSELS TOWED	Empty	Loaded	Total	25b. TOTAL H.P. OF TOWING UNITS	25c. MAXIMUM SIZE OF TOW WITH TOW-BOAT(S)	Length	Width	25d. (Describe in Block 44.)
									☐ PUSHING AHEAD ☐ TOWING ASTERN ☐ TOWING ALONGSIDE ☐ MORE THAN ONE TOW-BOAT ON TOW

SECTION II. BARGE INFORMATION

26. Name	26a. Official Number	26b. Type	26c. Length	26d. Gross Tons	26e. USCG Certificate of Inspection Issued at:

26f. Year Built	26g. ☐ SINGLE SKIN ☐ DOUBLE SKIN	26h. Draft FWD	AFT	26i. Operating Company

26j. Damage Amount	26k. Describe Damage to Barge
BARGE $ _____ CARGO $ _____ OTHER $ _____	

PREVIOUS EDITIONS MAY BE USED

SN 7530-00-FO1-1730

Figure 2. CASMAIN data form (Continued)

REVERSE OF CG-2692 (REV. 6-87)

SEC N III. PERSONNEL ACCIDENT INFORMAT

27. Person Involved ☐ MALE or ☐ FEMALE ☐ DEAD ☐ MISSING ☐ INJURED	27a. Name (Last, First, Middle Name)	27c. Status ☐ CREW ☐ PASSENGER ☐ OTHER (Specify)
	27b. Address (City, State, Zip Code)	

28. Birth Date	29. Telephone No. ( )	30. Job Position	31. (Check here if off duty) ☐

32. Employer (If different from Block 18., fill in Name, Address, Telephone No.)

33. Person's Time	YEAR(S)	MONTH(S)	34. Industry of Employer (Towing, Fishing, Shipping, Crew Supply, Drilling, etc.)
A. IN THIS INDUSTRY			
B. WITH THIS COMPANY			
C. IN PRESENT JOB OR POSITION			35. Was the Injured Person Incapacitated 72 Hours or More? ☐ YES ☐ NO
D. ON PRESENT VESSEL/FACILITY			
E. HOURS ON DUTY WHEN ACCIDENT OCCURRED			36. Date of Death

37. Activity of Person at Time of Accident

38. Specific Location of Accident on Vessel/Facility

39. Type of Accident (Fall, Caught between, etc.)	40. Resulting Injury (Cut, Bruise, Fracture, Burn, etc.)
41. Part of Body Injured	42. Equipment Involved in Accident

43. Specific Object, Part of the Equipment in Block 42., or Substance (Chemical, Solvent, etc.) that directly produced the Injury

SECTION IV. DESCRIPTION OF CASUALTY

44. Describe how accident occured, damage, information on alcohol/drug involvement and recommendations for corrective safety measures. (See instructions and attach additional sheets if necessary).

45. Witness (Name, Address, Telephone No.)

46. Witness (Name Address, Telephone No.)

SECTION V PERSON MAKING THIS REPORT

47. Name (PRINT) (Last, First, Middle)	47b. Address (City, State, Zip Code)	47c. Title
		47d. Telephone No. ( )
47a. Signature		47e. Date

FOR COAST GUARD USE ONLY	REPORTING OFFICE:

APPARENT CAUSE

CASUALTY CODE A B C	INVESTIGATOR (Name)	DATE	APPROVED BY (Name)	DATE

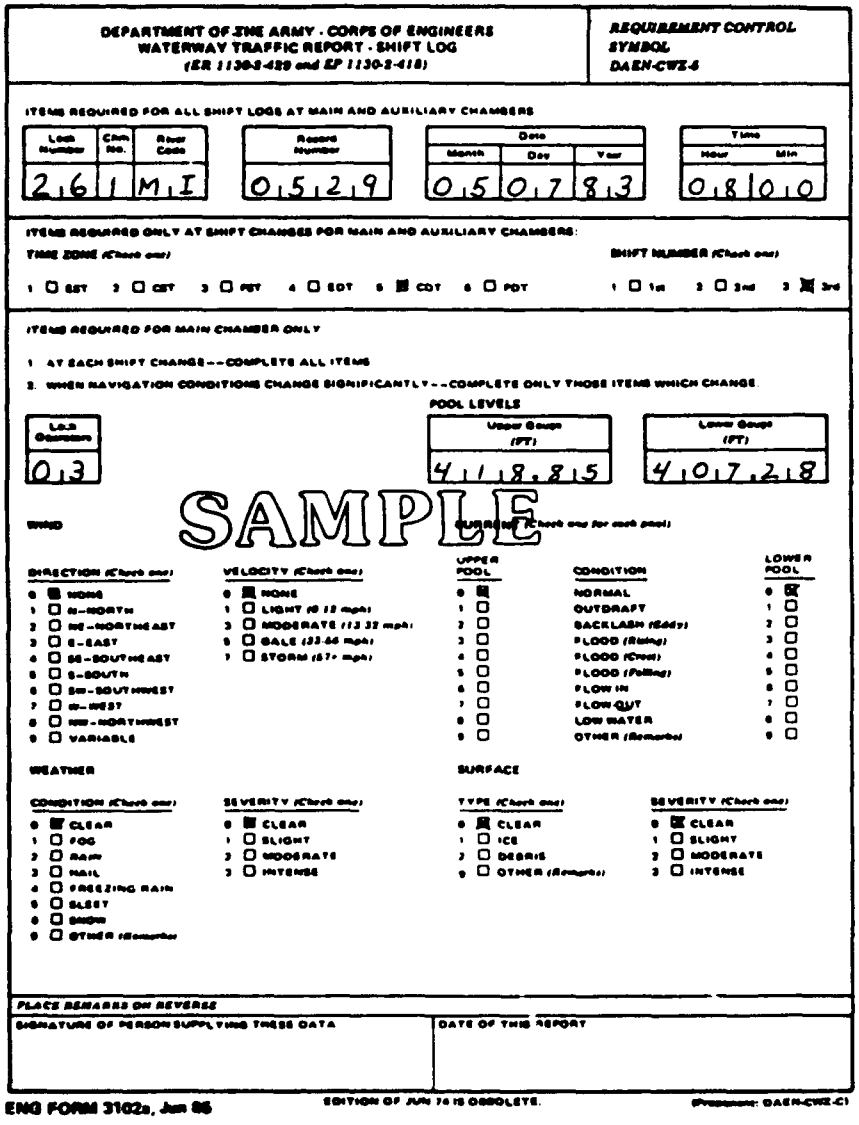
Figure 2. (Concluded)

through the lock as well as the physical aspects of lockages. A form is completed by the lock master for each lockage (Figure 3). One item in the data set is a stall code, which identifies accidents as a cause of excessive delay during a lockage. While PMS does not provide direct cost of accident data, the data base is used in the subsequent phase of the study, which focuses on delay estimates.

District Records

16. Following the pilot studies comparing SIMS and CASMAIN to St. Louis District records, contacts were made with numerous Districts to confirm that each had a local record system similar to the one maintained within the St. Louis District. Since these type records were available in each District, the decision was made to use local records because of their comprehensive and thorough source of accident cost information to determine direct accident cost estimates.

17. Seven Corps of Engineers District Offices were surveyed: St. Paul, Rock Island, Huntington, St. Louis, Louisville, Pittsburgh, and Nashville. The survey includes up to 11 years of data, 80 locks, and 10 rivers. Table 1 lists each District, years of data, number of locks in each District, and names of rivers surveyed. Accident data reflecting the severity and frequency of vessel collision to USACE lock facilities, specifically to miter gates, were collected: the lock name, the date of accident, the direction of the vessel, whether a miter gate was struck, which miter gate was struck, and the amount of damage to Government property (either real or estimated). dBase III data management software was used to develop a data base for storage and retrieval of all District records (dBase III, no date).



DEPARTMENT OF THE ARMY · CORPS OF ENGINEERS
WATERWAY TRAFFIC REPORT · SHIFT LOG
(ER 1130-2-429 and EP 1130-2-418)

REQUIREMENT CONTROL SYMBOL
DAEN-CWZ-S

ITEMS REQUIRED FOR ALL SHIFT LOGS AT MAIN AND AUXILIARY CHAMBERS

Lock Number	Chamber No.	River Code	Record Number	Date: Month	Date: Day	Date: Year	Time: Hour	Time: Min
2 6	1	M I	0 5 2 9	0 5	0 7	8 3	0 8	0 0

ITEMS REQUIRED ONLY AT SHIFT CHANGES FOR MAIN AND AUXILIARY CHAMBERS:

TIME ZONE (Check one)
1 ☐ EST 2 ☐ CST 3 ☐ MST 4 ☐ EDT 5 ■ CDT 6 ☐ PDT

SHIFT NUMBER (Check one)
1 ☐ 1st 2 ☐ 2nd 3 ☒ 3rd

ITEMS REQUIRED FOR MAIN CHAMBER ONLY

1. AT EACH SHIFT CHANGE--COMPLETE ALL ITEMS
2. WHEN NAVIGATION CONDITIONS CHANGE SIGNIFICANTLY--COMPLETE ONLY THOSE ITEMS WHICH CHANGE

Lock Operator	POOL LEVELS: Upper Gauge (FT)	Lower Gauge (FT)
0 3	4 1 1 8 . 8 5	4 1 0 7 . 2 8

SAMPLE

WIND

CURRENT (Check one for each pool)

DIRECTION (Check one)	VELOCITY (Check one)	UPPER POOL	CONDITION	LOWER POOL
0 ■ NONE	0 ■ NONE	0 ■	NORMAL	0 ☒
1 ☐ N--NORTH	1 ☐ LIGHT (0 to 12 mph)	1 ☐	OUTDRAFT	1 ☐
2 ☐ NE--NORTHEAST	2 ☐ MODERATE (13 to 32 mph)	2 ☐	BACKLASH (Eddy)	2 ☐
3 ☐ E--EAST	3 ☐ GALE (33-56 mph)	3 ☐	FLOOD (Rising)	3 ☐
4 ☐ SE--SOUTHEAST	4 ☐ STORM (57+ mph)	4 ☐	FLOOD (Crest)	4 ☐
5 ☐ S--SOUTH		5 ☐	FLOOD (Falling)	5 ☐
6 ☐ SW--SOUTHWEST		6 ☐	FLOW IN	6 ☐
7 ☐ W--WEST		7 ☐	FLOW OUT	7 ☐
8 ☐ NW--NORTHWEST		8 ☐	LOW WATER	8 ☐
9 ☐ VARIABLE		9 ☐	OTHER (Remarks)	9 ☐

WEATHER

CONDITION (Check one)	SEVERITY (Check one)
0 ■ CLEAR	0 ■ CLEAR
1 ☐ FOG	1 ☐ SLIGHT
2 ☐ RAIN	2 ☐ MODERATE
3 ☐ HAIL	3 ☐ INTENSE
4 ☐ FREEZING RAIN	
5 ☐ SLEET	
6 ☐ SNOW	
9 ☐ OTHER (Remarks)	

SURFACE

TYPE (Check one)	SEVERITY (Check one)
0 ■ CLEAR	0 ☒ CLEAR
1 ☐ ICE	1 ☐ SLIGHT
2 ☐ DEBRIS	2 ☐ MODERATE
9 ☐ OTHER (Remarks)	3 ☐ INTENSE

PLACE REMARKS ON REVERSE

SIGNATURE OF PERSON SUPPLYING THESE DATA

DATE OF THIS REPORT

ENG FORM 3102a, Jun 86 EDITION OF JUN 74 IS OBSOLETE. (Proponent: DAEN-CWZ-C)

DEPARTMENT OF THE ARMY · CORPS OF ENGINEERS
WATERWAY TRAFFIC REPORT · LOCKAGE LOG
(ER 1130-2-429 and EP 1130-2-418)

REQUIREMENT CONTROL SYMBOL
DAEN-CWZ-S

Vessel Name	Vessel Number	Lock Number	Chamber No.	Record Number
SUNFLOWER	1 2 3 7 6 5 4	2 6	1	0 5 3 0

DIRECTION
■ UP
☐ DOWN

LOCKAGE CUTS
01 ☐ SINGLE (One cut)
02 ■ DOUBLE (Two cuts)
03 ☐ TRIPLE (Three cuts)
04 ☐ QUADRUPLE (Four cuts)
☐ MORE THAN FOUR (4) CUTS (Complete number of cuts)

TYPE
S ■ STRAIGHT
V ☐ SETOVER
J ☐ JACK KNIFE
K ☐ KNOCKOUT
M ☐ MULTIVESSEL
F ☐ FAST DOUBLE
P ☐ NAVIGABLE PASS
O ☐ OPEN PASS
Y ☐ BARGE TRANSFER
Z ☐ OTHER (Remarks)

VESSEL TYPE
T ■ COMMERCIAL TOWBOATS
P ☐ PENGR. BOATS, FERRIES
R ☐ RECREATIONAL VESSELS
C ☐ CARGO CARRYING VESSELS
G ☐ U.S. GOVT VESSELS
U ☐ U.S. GOVT CONTRACTOR
F ☐ COMMCL. FISHING BOATS
Z ☐ OTHER (Remarks)
L ☐ LIGHT (Towboat w/o Barges)

Light-Common Gauge	Rec. Veh.	Passengers
[redacted]	[redacted]	[redacted]

SAMPLE

LOCKAGE TIMES

ENTRY TYPE
☐ FLY ENTRY
■ EXCHANGE ENTRY
☐ TURNBACK ENTRY

EXIT TYPE
☐ FLY EXIT
☐ EXCHANGE EXIT
■ TURNBACK EXIT

	Arrival: Date Month	Arrival: Date Day	Arrival: Time Hour	Arrival: Time Min	Start of Lockage Hour	Start of Lockage Min	Gate Over Sill Hour	Gate Over Sill Min	End of Entry Hour	End of Entry Min	Start of Exit Hour	Start of Exit Min	End of Lockage Hour	End of Lockage Min
First Cut	0 1	1 2	0 8	2 7	1 4	2 8	1 4	3 3	1 4	5 0	1 5	0 3	1 5	0 7
Last Cut	[redacted]				1 5	2 1	1 5	2 2	1 5	2 5	1 5	3 8	1 6	0 2

STALL OR INTERFERENCE

Begin Stall: Month	Begin Stall: Day	Begin Stall: Hour	Begin Stall: Min	End Stall: Month	End Stall: Day	End Stall: Hour	End Stall: Min
0 1	1 2	1 5	1 4	0 1	1 2	1 5	1 4

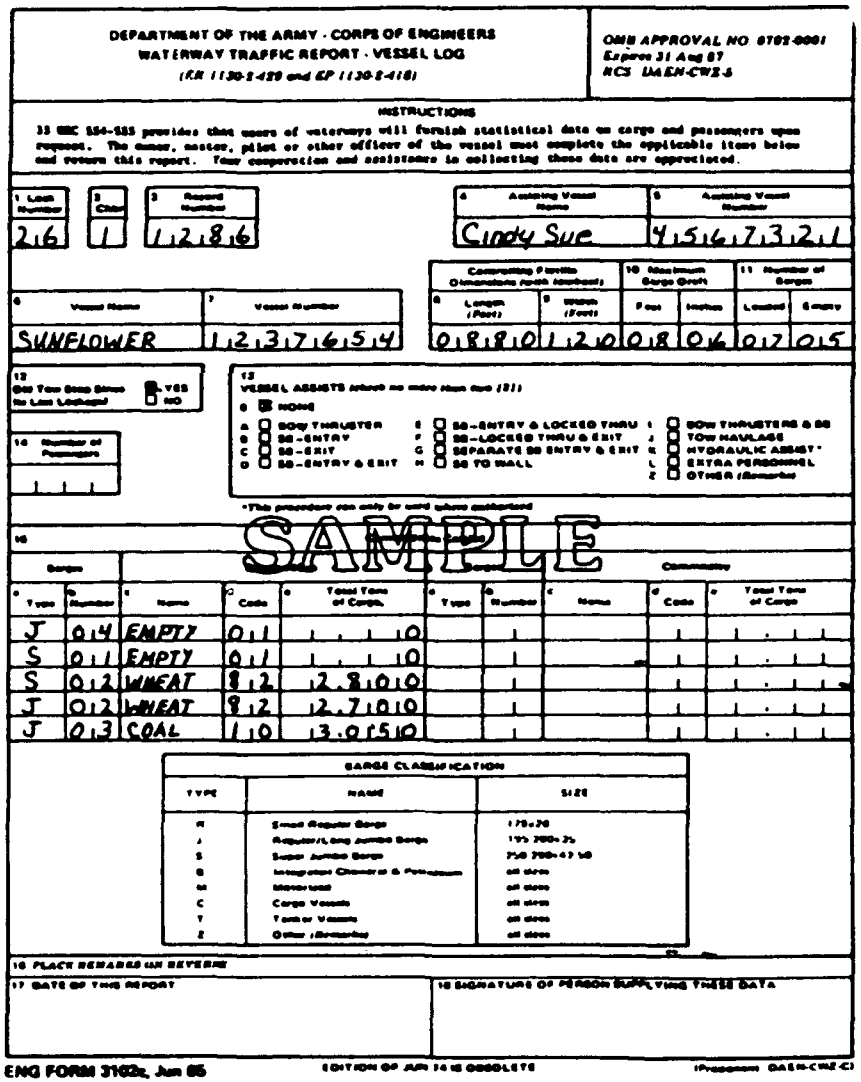
STALL CODE (Check only one)

WEATHER	SURFACE	TOW	LOCK	OTHER
A ☐ FOG	H ☐ ICE	C ☐ INTERFERENCE BY OTHER VESSELS	O ☐ DEBRIS IN LOCK	V ☐ TOW DETAINED BY CORPS OR COAST GUARD
B ☐ RAIN	I ☐ RIVER CURRENT OR OUTDRAFT	L ☐ TOW MALFUNCTION/ BREAKDOWN	R ☐ HOWR MALFUNCTION	W ☐ COLLISION/ ACCIDENT
C ■ SLEET OR HAIL	J ☐ FLOOD	M ☐ TOW STAFF ELSEWHERE OCCUPIED	S ☐ STAFF ELSEWHERE	X ☐ VEHICULAR OR R.R. BRIDGE
D ☐ SNOW			T ☐ TESTING OR MAINTENANCE	Z ☐ OTHER (Remarks)
E ☐ WIND				

PLACE REMARKS ON REVERSE

ENG FORM 3102b, Jun 86 EDITION OF JUN 74 IS OBSOLETE (Proponent: DAEN-CWZ-C)

Figure 3. Five logs constituting the Waterway Traffic Report (Sheet 1 of 3)



DEPARTMENT OF THE ARMY · CORPS OF ENGINEERS
WATERWAY TRAFFIC REPORT · VESSEL LOG
(ER 1130-2-429 and EP 1130-2-418)

OMB APPROVAL NO 0702-0001
Expires 31 Aug 87
RCS DAEN-CWZ-6

INSTRUCTIONS

33 USC 554-555 provides that owners of waterways will furnish statistical data on cargo and passengers upon request. The owner, master, pilot or other officer of the vessel must complete the applicable items below and return this report. Your cooperation and assistance in collecting these data are appreciated.

1 Lock Number	2 Chart	3 Record Number	4 Assisting Vessel Name	5 Assisting Vessel Number
216	1	12816	Cindy Sue	4516732 1

6 Vessel Name	7 Vessel Number	Commercial Pleasure Dimensions (with towboat) Length (Feet)	Width (Feet)	10 Maximum Barge Draft Feet	Inches	11 Number of Barges Loaded	Empty
SUNFLOWER	1 2 3 7 6 5 4	0 1 8 8 0	1 2 0	0 8	0 6	0 7	0 5

12 Did Tow Pass Through Its Last Lock(age)? ☐ YES ☐ NO

13 VESSEL ASSISTS (Check no more than two (2))
☒ NONE
A ☐ BOW THRUSTER
B ☐ SB-ENTRY
C ☐ SB-EXIT
D ☐ SB-ENTRY & EXIT
E ☐ SB-ENTRY & LOCKED THRU
F ☐ SB-LOCKED THRU & EXIT
G ☐ SEPARATE SB ENTRY & EXIT
H ☐ SB TO WALL
I ☐ BOW THRUSTERS & SB
J ☐ TOW HAULAGE
K ☐ HYDRAULIC ASSIST*
L ☐ EXTRA PERSONNEL
Z ☐ OTHER (Remarks)
*This procedure can only be used where authorized

14 Number of Passengers: 1 1 1

SAMPLE

16 Barges — Commodity

Type	Number	Name	Code	Total Tons of Cargo	Type	Number	Name	Code	Total Tons of Cargo
J	014	EMPTY	011	10					
S	011	EMPTY	011	10					
S	012	WHEAT	812	2810 10					
J	012	WHEAT	812	2710 10					
J	013	COAL	110	3052 10					

BARGE CLASSIFICATION

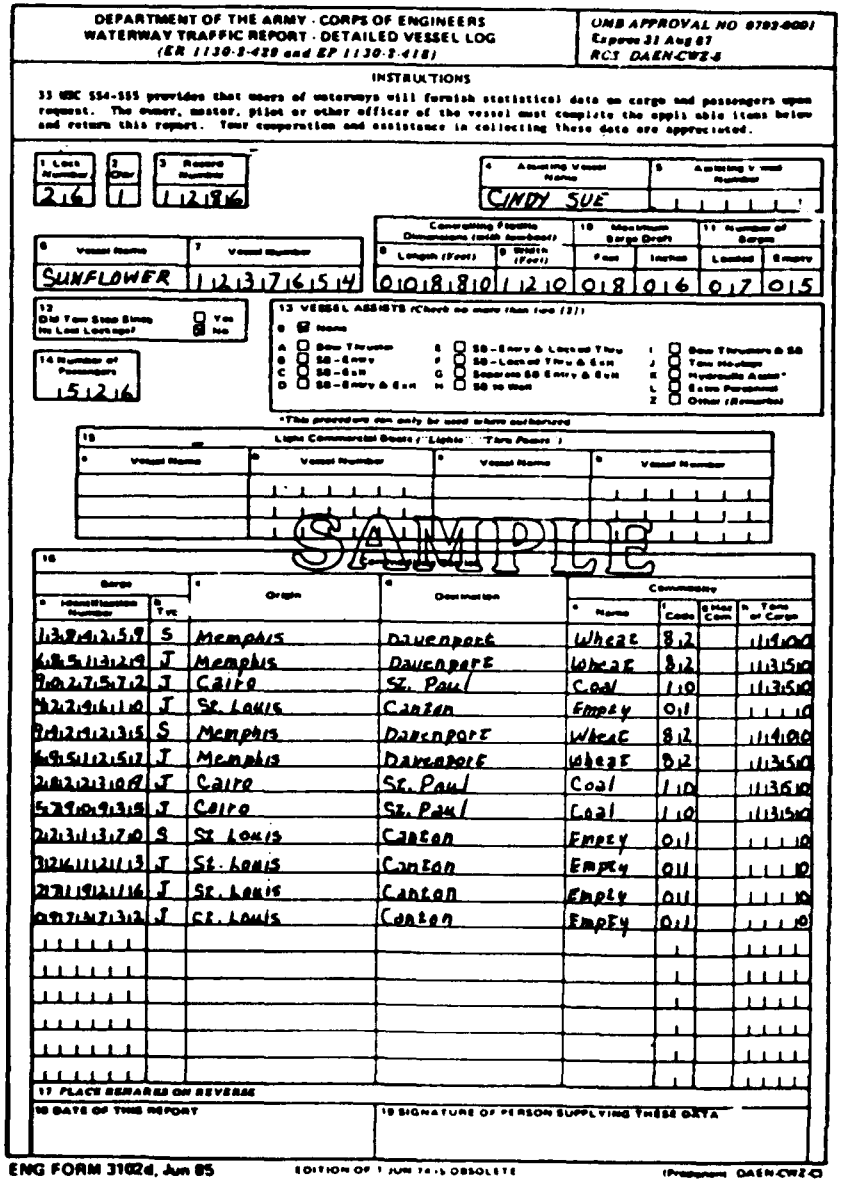
TYPE	NAME	SIZE
M	Small Regular Barge	175×26
J	Regular/Long Jumbo Barge	195×35
S	Super Jumbo Barge	250×52.5
B	Integrated Chemical & Petroleum	all sizes
M	Motorized	all sizes
C	Cargo Vessels	all sizes
T	Tanker Vessels	all sizes
Z	Other (Remarks)	all sizes

18 PLACE REMARKS IN REVERSE

17 DATE OF THIS REPORT

19 SIGNATURE OF PERSON SUPPLYING THESE DATA

ENG FORM 3102c, Jun 85 EDITION OF JUN 74 IS OBSOLETE (Proponent DAEN-CWZ-C)



DEPARTMENT OF THE ARMY · CORPS OF ENGINEERS
WATERWAY TRAFFIC REPORT · DETAILED VESSEL LOG
(ER 1130-2-429 and EP 1130-2-418)

OMB APPROVAL NO 0702-0001
Expires 31 Aug 87
RCS DAEN-CWZ-6

INSTRUCTIONS

33 USC 554-555 provides that owners of waterways will furnish statistical data on cargo and passengers upon request. The owner, master, pilot or other officer of the vessel must complete the applicable items below and return this report. Your cooperation and assistance in collecting these data are appreciated.

1 Lock Number	2 Chart	3 Record Number	4 Assisting Vessel Name	5 Assisting Vessel Number
216	1	12816	CINDY SUE	

6 Vessel Name	7 Vessel Number	Commercial Pleasure Dimensions (with towboat) Length (Feet)	Width (Feet)	10 Maximum Barge Draft Feet	Inches	11 Number of Barges Loaded	Empty
SUNFLOWER	1 2 3 7 6 5 4	0 1 8 8 0	1 2 0	0 8	0 6	0 7	0 5

12 Did Tow Pass Through Its Last Lock(age)? ☐ Yes ☒ No

13 VESSEL ASSISTS (Check no more than two (2))
☒ None
A ☐ Bow Thruster
B ☐ SB-Entry
C ☐ SB-Exit
D ☐ SB-Entry & Exit
E ☐ SB-Entry & Locked Thru
F ☐ SB-Locked Thru & Exit
G ☐ Separate SB Entry & Exit
H ☐ SB to Wall
I ☐ Bow Thrusters & SB
J ☐ Tow Haulage
K ☐ Hydraulic Assist*
L ☐ Extra Personnel
Z ☐ Other (Remarks)
*This procedure can only be used where authorized

14 Number of Passengers: 1 5 1 2 6

15 Light Commercial Boats ("Lights" "Tare Boats")

Vessel Name	Vessel Number	Vessel Name	Vessel Number

SAMPLE

16 Barges — Commodity

Identification Number	Type	Origin	Destination	Name	Code	Hazardous Cargo	Tons of Cargo
1328412559	S	Memphis	Davenport	Wheat	812		11910 00
6855113129	J	Memphis	Davenport	Wheat	812		11351 00
9062758712	J	Cairo	St. Paul	Coal	110		11351 00
3827491611 0	J	St. Louis	Canton	Empty	011		1 1 1 10
9482491213 5	S	Memphis	Davenport	Wheat	812		11910 00
6855113129	J	Memphis	Davenport	Wheat	812		11351 00
2882123108A	J	Cairo	St. Paul	Coal	110		11351 00
5291009135	J	Cairo	St. Paul	Coal	110		11351 00
2123113720	S	St. Louis	Canton	Empty	011		1 1 1 10
3126111211 3	J	St. Louis	Canton	Empty	011		1 1 1 10
2781191211 6	J	St. Louis	Canton	Empty	011		1 1 1 10
0971347312	J	St. Louis	Canton	Empty	011		1 1 1 10

17 PLACE REMARKS ON REVERSE

18 DATE OF THIS REPORT

19 SIGNATURE OF PERSON SUPPLYING THESE DATA

ENG FORM 3102d, Jun 85 EDITION OF 1 JUN 74 IS OBSOLETE (Proponent DAEN-CWZ-C)

Figure 3. (Sheet 2 of 3)

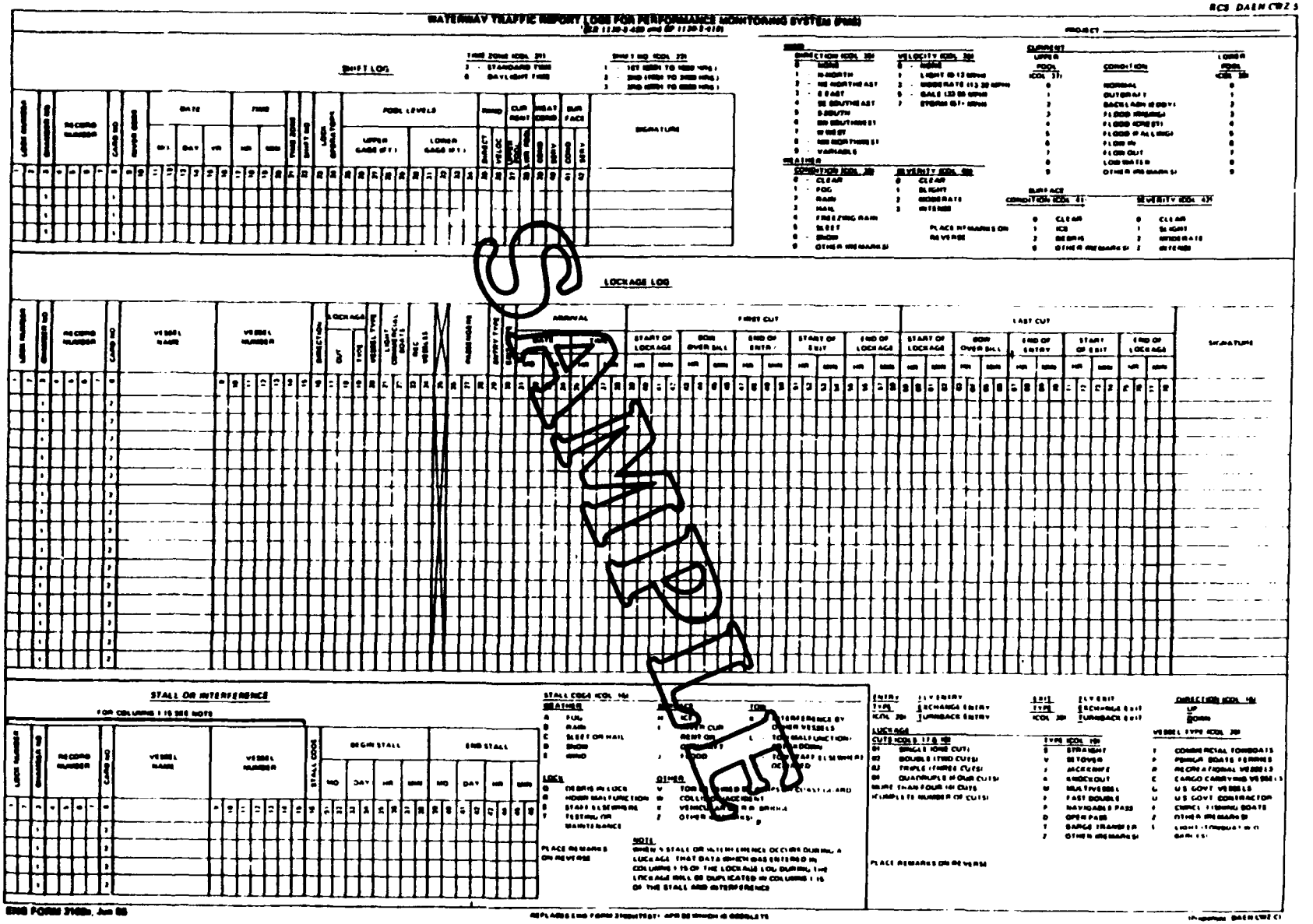


Figure 3. (Sheet 3 of 3)

PART III: ACCIDENT ANALYSIS AND DIRECT COSTS

18. Direct accident costs are defined in this study as those associated with the repair of the lock gate or other lock appurtenances damaged during an accident. Analysis of the District records identifies the locks that account for high accident rates and significant repair costs. Dollar damages reflect actual repair figures, when possible, or estimated damages if actual repair costs were not provided. Accidents reported without damage estimates were not included in statistical summaries. That is, only nonzero records were considered in the tables and the statistics included herein.

19. Table 2 contains the accident totals by District. Table 3 presents the totals by river. Many conclusions can be drawn from these two tables. St. Paul has the most number of accidents for the 10-year period while the St. Louis District spent the most money per lock on repairs. Rock Island has spent almost half a million dollars per year making repairs to locks damaged by collisions. More money is spent on repairs per lock on the Upper Mississippi River than on other rivers surveyed. The average cost for miter gate accidents is higher ($22,200 per accident) than for all accidents ($18,400).

20. Table 4 is a detailed listing containing the total number of accidents and damages at each lock. From this table several lists were compiled pertaining to data at individual locks. The 10 locks of the 80 surveyed with the highest number of miter gate accidents and the most accidents per year are found in Table 5, ranked in descending order according to the lock with the most miter gate accidents. While the average number of accidents per year is relatively low even at the high-accident locations, the damages associated with each accident can be quite costly, as seen in Table 6. Ranked according to miter gate damages, these statistics are based on locks having a minimum of five accidents during the period of record and include accidents that resulted in damages of less than $1,000. Economic data presented in Table 7 show the average annual damages for the top 10 locations based on all accidents; and Table 8, the average annual damages for miter gate accidents only. Table 9 lists the 10 locks with the highest total damages over the period of record in the survey.

21. Other statistics and facts taken from the data such as the total number of accidents, how many of these involved the miter gates, and total expenditures for these seven Districts, are scattered throughout these tables.

The number of miter gate accidents constitutes 57 percent of the total number of accidents for the period of record represented by the survey, yet comprises approximately 69 percent of the damages. The average cost per lock for all repairs is $157,500, while the average repair cost per lock for miter gates is only $108,800.

22. A catastrophic accident, as defined in this study, is any accident having damages greater than or equal to $50,000. This limit was arbitrarily selected by the authors. Table 10 lists each catastrophic accident including the District, lock name, date of accident, cost of repair or damage, and whether the accident involved a miter gate. A total of 61 accidents fell in this category producing a total damage figure of $9,677,700, or approximately 77 percent of the total damages of $12,596,600. Over 72 percent of the total number of catastrophic accidents occur to the miter gates. Of the 685 total reported accidents, the 44 accidents in the catastrophic category involving miter gates, or less than 7 percent, caused 60 percent of all reported damages.

23. Investigation of these tables can help identify locks where protection systems or modifications could provide potential savings. Four locks that rank among the top 10 in having the highest rate of accidents per year, cost of accident, average annual damages, and most total damages are Gallipolis, Lock and Dam 24, Lock and Dam 25, and Lock and Dam 22. Gallipolis Lock, on the Ohio River, which had the highest accident rate and the highest annual damages, is presently being replaced by two lock chambers with an improved alignment or approach to the locks. The other three high-cost/high-accident locks are on the Mississippi River and experience heavy traffic volumes, which may account for the high rate of accidents at these locks. (This study did not include the determination of how accidents relate to traffic volume at each lock. However, traffic volume data extracted from available PMS quarterly reports can be found in Appendix B.)

24. In this phase of the study, accident statistics identified the locks with the highest potential for operational improvement with the installation of lock barrier protection systems. These results also highlighted those locations that are leading candidates for further analysis related to delay costs.

PART IV: DELAYS

Introduction

25. The direct costs required to repair damage to Government property resulting from collisions with miter gates represent only part of the total costs associated with lock accidents. A second cost component, which can be of equal or greater magnitude, is the additional operating costs or losses experienced when vessels are delayed due to lock closure or service interruption. When service is interrupted at the locks along the inland waterway transportation system as a result of an accident, costs are accumulated by waiting tows.

26. Operating costs can include fuel, manpower, and insurance. Losses may relate to delayed delivery of commodities or needing to provide alternative means of transporting those commodities. The hourly cost to operate a towboat, fuel and manpower only, can be as high as $500 (Fleming, Wood, and Goodwin 1985). Some figures from industry estimate these delays ranging as high as $30,000 per day per tow.

27. Articles in *The Waterways Journal Weekly* repeatedly report incidents in which accidents result in long delays and closures that can damage industry. One article indicated that lock closures can cost up to $3 million per day in financial losses to barge transportation companies. A 4-day closure for repair of the gates at Gallipolis Lock in March 1986 resulted in an estimated loss of $550,000 to the towboat industry according to the Huntington District. In April 1984, the miter gates at Gallipolis Lock and Dam on the Ohio River sustained extensive damage from a collision that required the lock to close for 17 days at an estimated cost to industry of $1.96 million. In addition to a $600,000 repair bill to the gates, an accident at Lock and Dam 25 on the Upper Mississippi River on 24 August 1985 caused a 5-day closure of the facility. When the gates reopened, 17 downbound tows were awaiting lockage at Lock and Dam 24 and 9 were waiting at Lock and Dam 25. As recently as 12 September 1989, a mishap occurred at Lock and Dam 26 in which the lower gates were struck closing down the lock for repairs. Six days later 33 tows were still awaiting lockage. (Information taken from several articles found in *The Waterways Journal Weekly*.)

28. Although figures quantifying the actual cost of delays vary, one

thing is certain: delays are quite expensive! While it would be interesting to compile these costs and add them to the repair bills for a composite analysis, the subjective nature of the problem was beyond the scope of this study. The intent of this study was to assess the length of delays associated with accidents to miter gates, rather than the costs.

29. Complete records of delays experienced by all vessels at all locks on the inland waterway system are collected as part of the lock PMS. With this comprehensive data source available, it was hypothesized that by comparing delay records at specific locks for periods before and after the occurrence of a miter gate collision, the amount of extra delay due to the accident event could be determined (Figure 4). Further, by evaluating increases in delays for a number of occurrences, models could be developed to correlate anticipated delay increases with accident severity as represented by the dollar amount of damage to the lock structure.

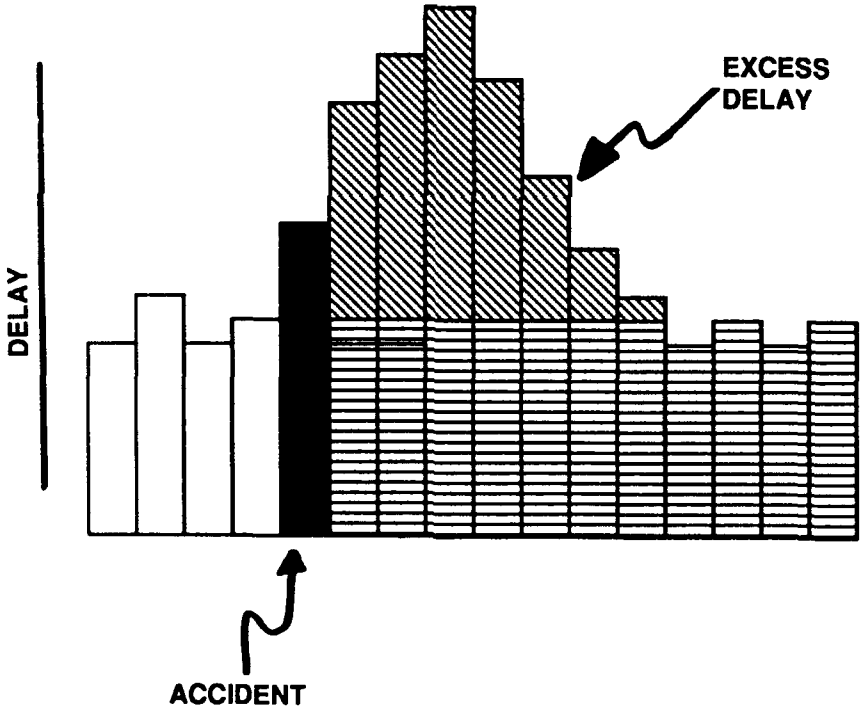


Figure 4. Hypothetical model of delays due to accidents

Methodology

30. The PMS data elements that indicate the amount of delay experienced by each vessel passing through the locks are the wait time, processing time,

and transit time. In PMS these terms are defined as follows:

a. Wait time. The time elapsed from the arrival of a vessel at a lock to the start of its approach to a lock chamber; the time spent in queue awaiting lockage.

b. Processing time. The time to process a vessel completely through a lock, from start of lockage to end of lockage.

c. Transit time. The sum of the wait time and processing time for a vessel.

31. Additionally, for each lockage, all stoppages in lock operation are recorded and assigned a stall code. One of the stall code items identifies stalls resulting from accidents. The objective then was to find all data records that contained the accident stall code and relate this information to the transit time and ultimately to delays due to accidents.

32. The initial step in this process was to access the PMS data base and extract the items required to perform the delay analysis. After review of the PMS User's Manual (Fleming, Wood, and Goodwin 1985), it was determined that "PMS Summary Report 18--Tow Transit Analysis: Detailed Lock Report" (PMS, no date) contained the required information. This report analyzed the performance of all vessels transiting the inland waterways on a lock-by-lock basis during a specified reporting period. The data are organized by individual locks on a month-by-month basis. Table 11 lists the data items in this report.

33. The records were downloaded from the PMS data base on the Control Data Corporation mainframe computer using a FORTRAN program written specifically for that purpose (Appendix C), and manipulated to be included in the dBase III data base of District accident records. The files were sorted according to date and time of each arriving vessel. Pleasure craft were eliminated from the analysis.

34. Regression analysis of arrival frequency and wait time data at each lock for several months of data was performed. The statistical package, MINITAB, was used for this analysis on the Memphis State University mainframe Univac computer (Minitab, Inc., no date).

Results

35. To determine the applicability of the methodology, two locks were selected for analysis, Lock 24 and Lock 25 on the Upper Mississippi River in the St. Louis District. Both of these locations were among the high-accident

locations identified in the direct-cost phase of this investigation. Additionally, they were selected because they are single-chamber locks, making analysis procedures less complex than at locations with dual-chamber locks.

36. Tables 12 and 13 list the dates and dollar amounts of damage of all the accidents involving collisions with miter gates at these two locks as reported by the St. Louis District. The PMS data base was accessed to obtain reports for the months during which these accidents occurred. However, gaps in the PMS records were detected and reports for all months could not be generated. Also indicated in these tables are the months for which PMS Report 18 was available and accidents reported for the two locks.

37. For each month where PMS data were available, a dBase III data file was created using the procedures described in the previous section. Each data file contained the name of each vessel arriving during the month, the date and time of arrival, the wait time and process time at the lock, and additional information entered in the PMS regarding stall time and stall code.

38. The initial analysis examined the variation in delays recorded prior to and subsequent to an accident event. Five representative accidents were selected for analysis. For each of these accidents the wait time and process time were determined for the 30 vessels arriving before the accident and for the 30 vessels arriving after the accident. Average delays (consisting of the total of wait and process times) for the 30 vessels arriving before the accident and the next 5, 10, and 20 vessels arriving after the accident were calculated. The results are shown in Table 14.

39. It was hypothesized that delays would increase after an accident, and that a pattern would emerge that indicated the extra delay, in terms of increased wait and process times, resulting from the accident. A review of the delay calculations for the five accidents listed in Table 14 indicated that a consistent pattern did not emerge. For two of the accidents with damage under $3,000, delays actually were lower after the accident than before the accident. One accident with an estimated damage of $1,250 showed a slight increase in delays for the 5 vessels arriving after the incident but little change in average delay after 20 arrivals. In two cases, one involving a major accident with an estimated damage of $208,365, and one with minor damage of $1,012, delays increased after the accident. The largest increase in post-accident delay for these five accidents occurred after the $1,012 accident. Figures 5-9 illustrate the individual vessel delay patterns for arrival

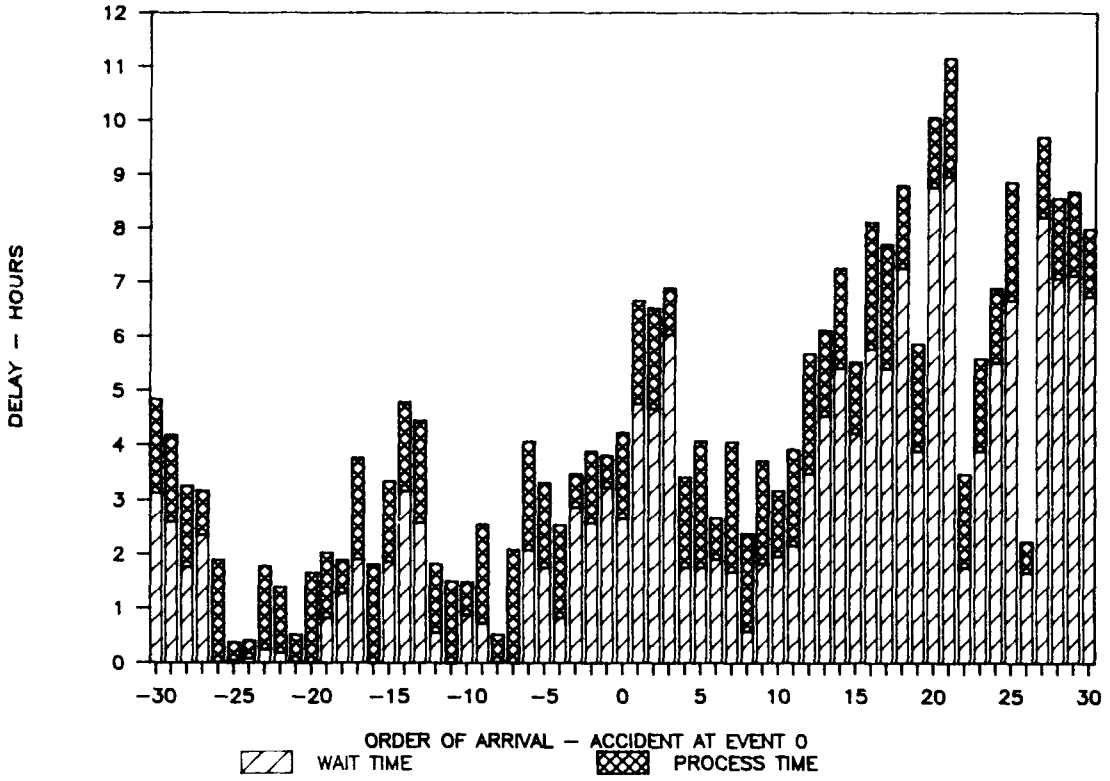


Figure 5. Individual vessel delay, Lock 24, $208,565 accident on 7/27/80

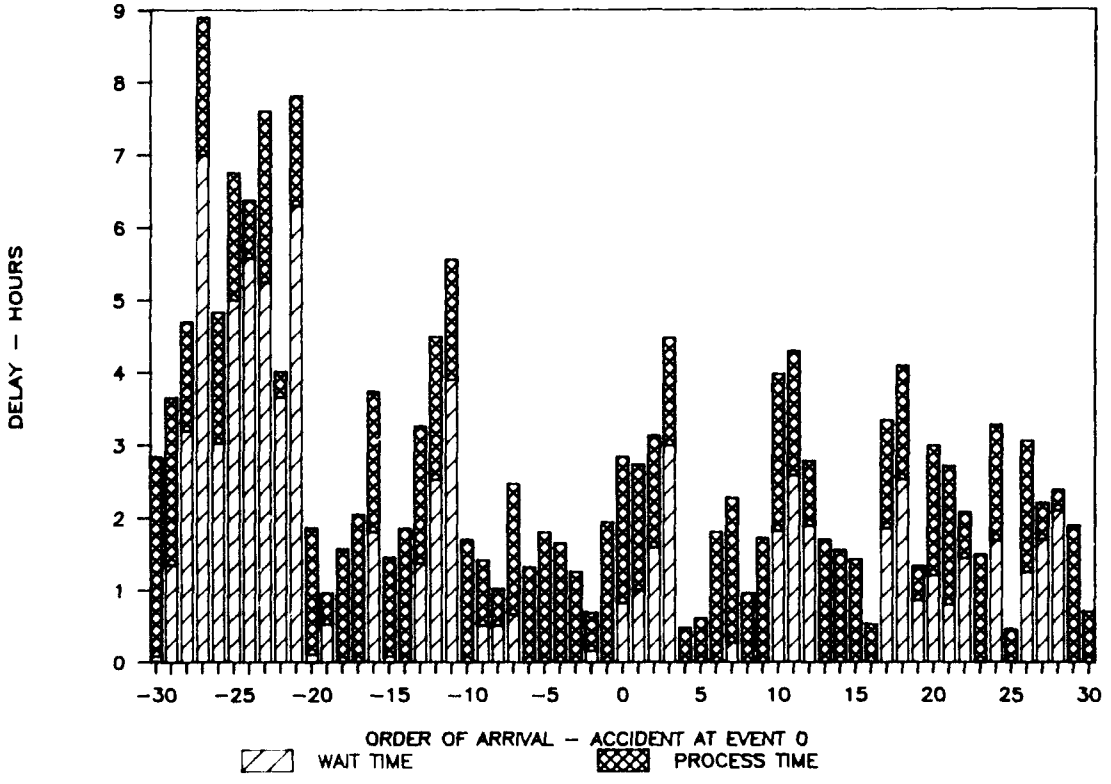


Figure 6. Individual vessel delay, Lock 24, $2,387 accident on 9/24/84

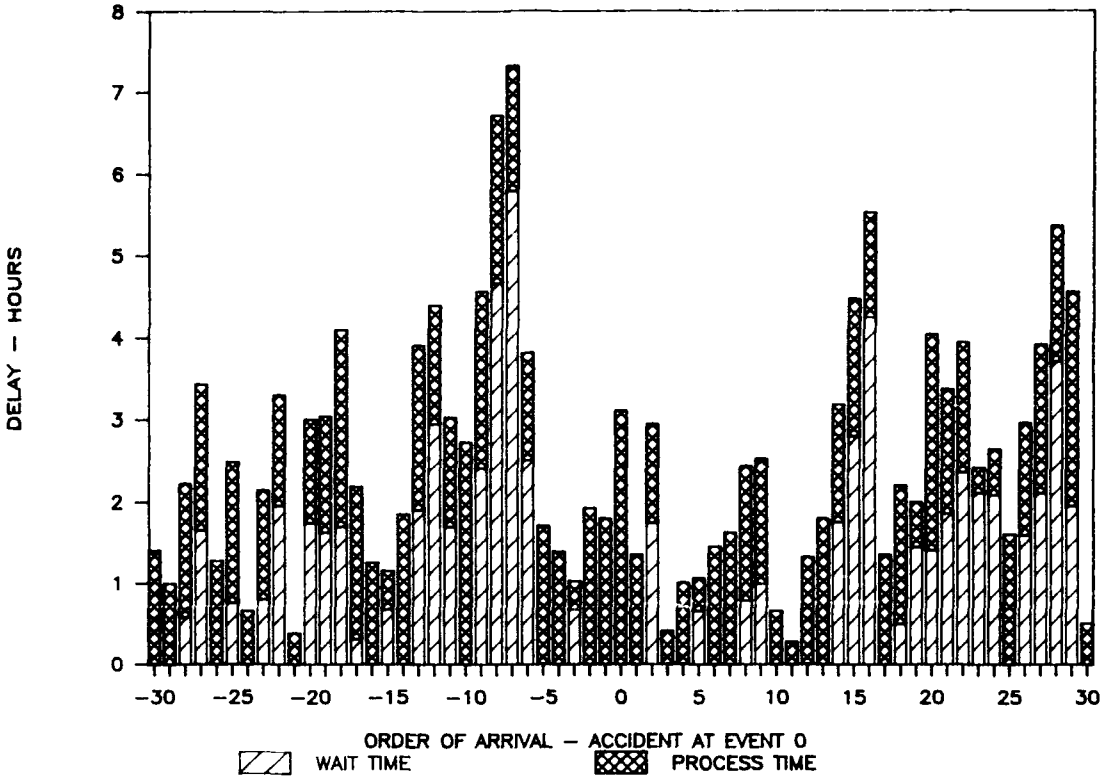


Figure 7. Individual vessel delay, Lock 24, $680 accident on 5/18/86

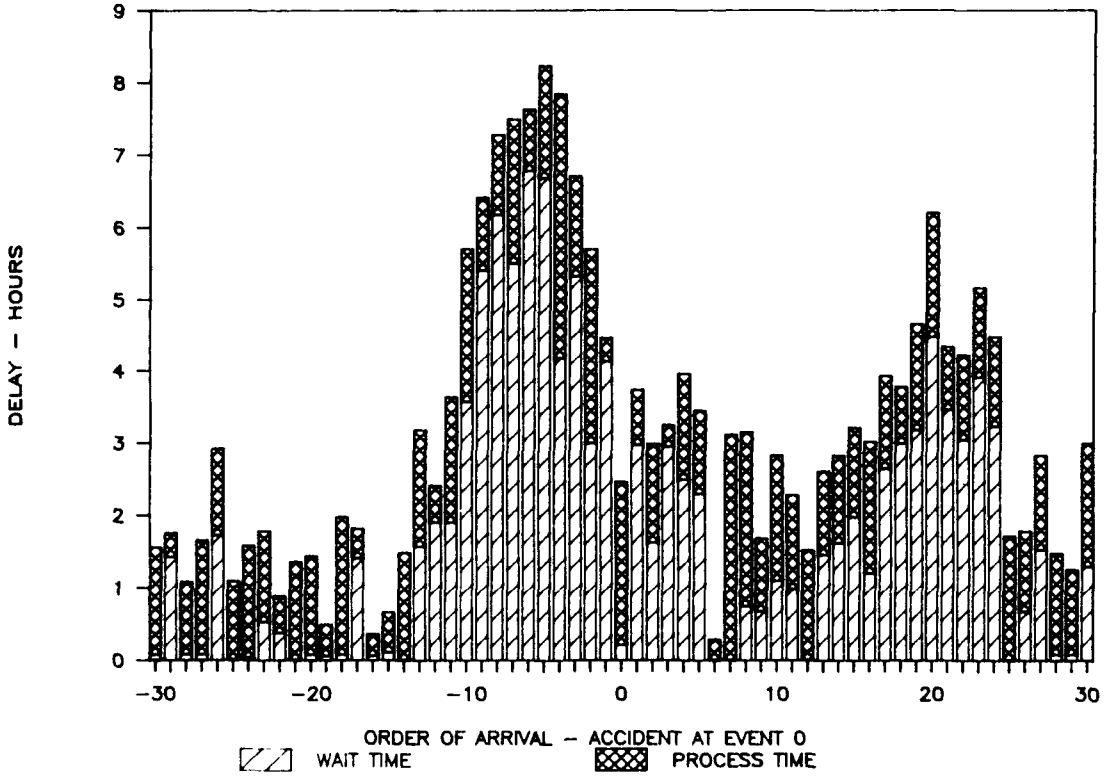


Figure 8. Individual vessel delay, Lock 25, $1,250 accident on 5/27/83

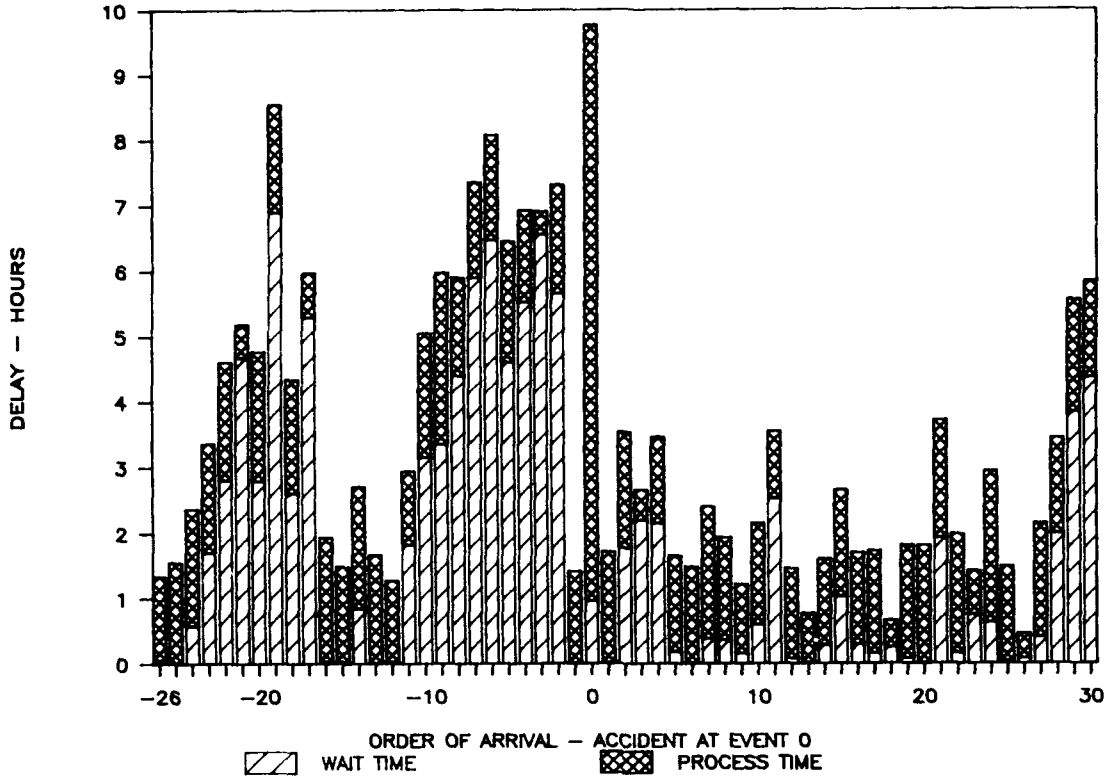


Figure 9. Individual vessel delay, Lock 25, $1,012 accident on 7/3/85

before and after the five miter gate accidents listed in Table 14.

40. This result indicated that additional factors, such as the arrival rates per day before and after the accident, the severity of the accident, or other reasons for stalls at locks, may influence the delays experienced after an accident as significantly as the occurrence of a collision with a miter gate. To examine the possible effects of the traffic pattern and the accident occurrence on delays, additional charts were developed relating average wait and process times per day for the entire month when there was an accident. These charts illustrate the daily variation in average wait times and process times per day and the number of vessel arrivals per day for representative months.

41. Two of these charts for Lock 24, one for the month of July 1980 and the other for October 1981, are shown in Figures 10 and 11, respectively. The chart for July 1980 shows a definite increase in wait times after the accident. The October 1981 chart does not indicate a definite pattern of wait times relating to the collision, which caused only $5,828 in damage to the lock structure. Appendix D contains additional charts developed for other months with miter gate accidents at both Locks 24 and 25. Wide variations in

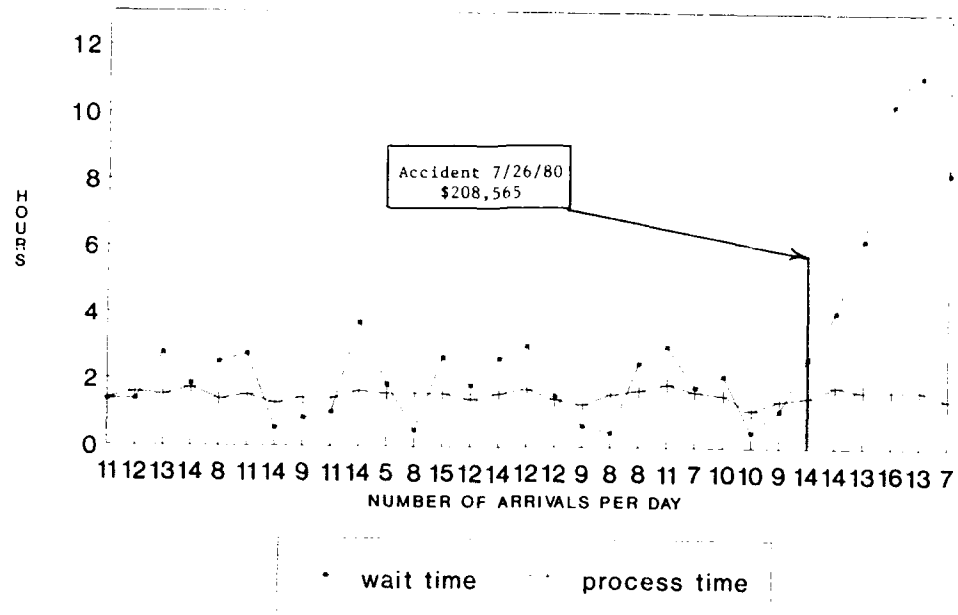


Figure 10. Variation in average daily lock delays, Lock 24, July 1980

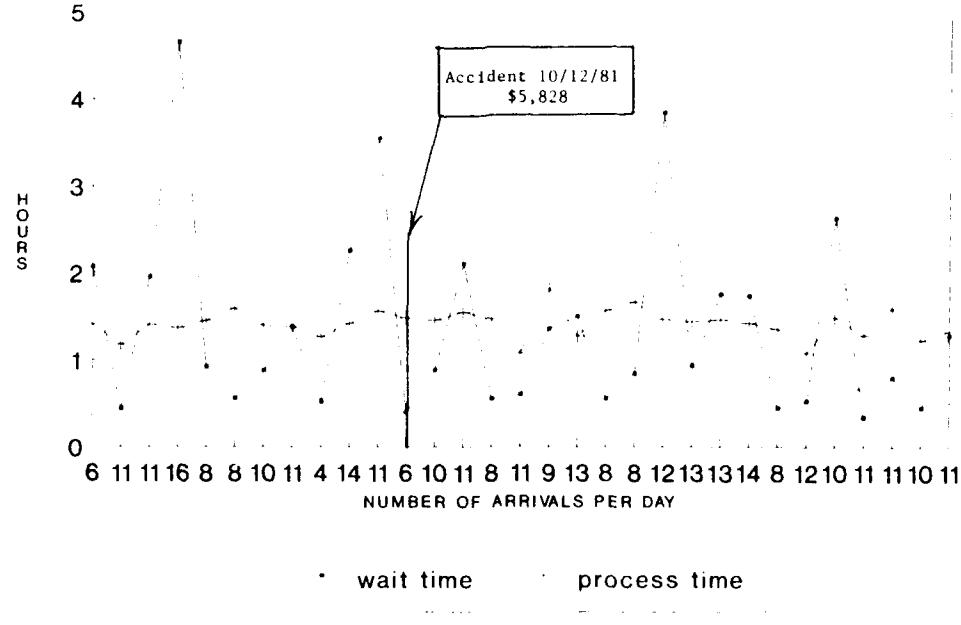


Figure 11. Variation in average daily lock delays, Lock 24, October 1981

delay patterns are evident in these plots. For some accidents, primarily those of high severity as indicated by the damage estimates, delays following an accident build up as expected. However, no generalizations could be deduced from these charts because in other instances the occurrence of an accident did not appear to be related to the buildup of additional delays.

42. As an example, an accident could occur that caused severe damage to the gates, but lock operation could continue until the spare gates were installed. According to Little Rock District personnel, the delay associated with replacing the miter gates with spare gates could take 18 to 21 days, which would be repeated when the repaired miter gates were reinstalled.

43. Conversely, an accident that incurs no damages could in fact cause delays. A case in point was observed by the author on 28 January 1988 at Murray Lock and Dam on the Arkansas River. A tow locking through became wedged in the lock chamber due to a massive drift raft caught between the barges and lock wall. This incident resulted in a 2-hr delay for the tow while lock personnel removed the drift, but resulted in no damages to the structure. Had there been other tows awaiting lockage, this would have caused a temporary delay in the total river queue.

44. An attempt was made to determine if regression equations could be developed to predict delays as a function of independent variables such as the year and month of the accident (seasonal variations), frequency of arrivals (traffic volume), and four types of stall codes contained in the PMS reports (accident, river currents, testing, and other). Several different transformations of the variables were attempted, but the results were disappointing. The highest R-squared coefficient, using data from Lock 25, was 0.45 for a multiple regression equation that determined wait times as a function of several independent variables. Based on this limited analysis, it was concluded that the regression equation developed was not satisfactory for use in predicting the delays experienced at Lock 25 during the months that had an accident event.

45. The principal objective was to construct a model of the excess delay experienced by tows awaiting passage through a lock that are required to wait as a result of a collision of a vessel with a miter gate. However, attempts to determine a relationship between delays and selected independent variables were not achieved. The lack of a predictable pattern may be due to one or more of the following reasons:

a. The miter gate accidents analyzed may not have been of a magnitude sufficient to interrupt service at the lock.

b. Damages may not have required immediate attention and repairs may have been postponed until a later date.

c. The rate of arrivals at the lock or the river conditions also cause increases in delays at locks. Quantification of the contributions due to these conditions is difficult with the data available for this study.

d. Depending on the severity of the accident and/or lock closure and on available alternatives, the towing industries could choose to reroute commodities in such a way that delays are not reflected in the PMS data.

e. Finally, inconsistencies were found in the PMS data, especially regarding identification of the stall codes.

46. The analysis of delay data proved to be disappointing. Review of delay records prior to and after several accident events resulted in no discernible pattern of delay increase that could be attributed solely to the accident. While some accidents, primarily those of high severity, conformed to an anticipated pattern of delay buildup and decay, other incidents did not.

PART V: CONCLUSIONS AND RECOMMENDATIONS

47. This accident study has produced a data base containing information on the frequency and severity of accidents at locks. Many of the tables presented in this report contain data and statistics that have not been previously compiled.

48. The two obvious conclusions from this study are that vessel collisions with USACE structures are both costly and frequent. Based on information obtained from the seven Districts surveyed, approximately $13 million was spent on repairs during a 7- to 11-year period. The average cost per accident to repair the structure was approximately $18,000. During this period, 685 accidents were reported for 80 locks. While it is apparent from the tables that damages, or direct costs, resulting from accidents are a significant portion of accident cost, other costs, particularly those related to delays, can cause yet an even greater financial burden to the transportation industry.

49. One study objective not fully accomplished was the development of a risk assessment methodology, that is, a benefit-to-cost analysis for use in conjunction with determining the costs that would be eliminated with the implementation of lock gate barrier systems. Underlying the methodology was the assumption that the true cost of an accident can be determined and is the composite of the damage to the lock structure, the damage to the vessel and its cargo, and the costs associated with excess delays. While the lock repair damages are specifically quantified in this study, the vessel and cargo damages and the delay costs have been determined only qualitatively.

50. A larger data set containing wait times before and after accidents could determine actual delay increases due to accidents. It is recommended that any additional research in this area also include analysis of lock operations in months where accidents did not occur. Additionally, the analysis should include the examination of queue buildup and delays at single- and multiple-chamber locks for other types of stall codes. With a more extensive data base, multiple regression equations that predict delays as a function of stall type and duration, arrival frequency, measurements of volume as a percentage of lock capacity, and/or other factors could be determined.

51. In summary, this study has presented some pertinent data regarding accident frequencies and severities at 80 locks on 10 rivers in 7 USACE

Districts. These data can be used to provide insight to operational problems at locks and in navigation planning studies. The data presented herein can be used as a basis for economic evaluation of alternatives regarding the prevention of accidents at locks and particularly those occurring at the miter gates.

REFERENCES

CASMAIN, US Coast Guard, CASMAIN Data, Marine Investigation Division, Washington, DC.

dBase III. Ashton-Tate, Culver City, CA 90230.

Fleming, Marilyn V., Wood, Donna E., and Goodwin, Robert J. 1985 (Aug). "Lock Performance Monitoring System; User's Manual for Data Collection and Editing," User Manual 85-UM-1, US Army Engineer Institute for Water Resources, Fort Belvoir, VA (Restricted to distribution within the Corps).

Martin, Sandra K. 1988 (Mar). "Interim Guidance on Lock Gate Barrier Systems," REMR Technical Note HY-N-1.4, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

_____. 1989 (Mar). "Effects of Geometry on the Kinetic Energy of a Towboat and Barges in a Navigation Lock," Technical Report REMR-HY-4, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Martin, Sandra K., and Holmes, Randy. 1989 (Jun). "Retrofit of a Towboat Arrester System on a Navigation Lock," Design of Hydraulic Structures 89, Second International Symposium on Design of Hydraulic Structures, Fort Collins, CO, M. Albertson and R. Kia, ed., sponsored by Colorado State University and the American Society of Civil Engineers, published by A. A. Balkema, Rotterdam, The Netherlands.

Minitab, Inc. 3031 Enterprise Drive, State College, PA 16801.

PMS, US Army Engineer Institute for Water Resources, Performance Monitoring System, Water Resources Support Center, Fort Belvoir, VA.

SIMS, US Army Corps of Engineers Safety Office, Safety Information Management System, Washington, DC 20314.

The Waterways Journal Weekly, Various issues from 1985-1989, The Waterways Journal, Inc., St. Louis, MO.

US Army Engineer Division, Ohio River. 1981 (Jul). "A Study of 427 Navigation Accidents at Ohio River Locks and Dams," Cincinatti, OH.

Table 1

General Data in District Survey

District Name and Symbol	Period of Records	Years of data	Number of Locks*	River Name
Huntington (ORH)	01/77-03/87	11	6	Ohio
			3	Kanawha
Louisville (ORL)	01/79-05/87	8	8	Ohio
			2	Green
Nashville (ORN)	04/81-03/87	6	8	Tennessee
			1	Cumberland
Pittsburgh (ORP)	12/79-05/87	8	6	Ohio
			3	Allegheny
			6	Monongahela
Rock Island (NCR)	04/78-11/86	10	12	Upper Mississippi
			8	Illinois
St. Louis (LMS)	08/79-11/86	7	4	Upper Mississippi
			1	Kaskaskia
St. Paul (NCS)	04/77-08/87	10	12	Upper Mississippi
			Total 80	

* Only locks where accidents were reported were included in the statistics.

Table 2

Totals by District

District (Number of Locks)	All Accidents			Miter Gates Only		
	Number	Total Cost, $	Average Cost, $/Lock	Number	Total Cost, $	Average Cost, $/Lock
ORH (9)	117	2,813,869	312,652	67	2,454,458	272,718
ORL (10)	60	871,686	87,169	31	416,083	41,608
ORN (9)	33	485,965	53,996	6	45,553	5,061
ORP (15)	59	642,169	42,811	10*	211,576*	14,105*
NCR (20)	145	4,834,682	241,734	85	3,441,050	172,052
LMS (5)	98	1,827,578	365,516	59	1,483,396	296,679
NCS (12)	173	1,120,672	93,389	134	653,680	54,473
Total (80)	685	12,596,621		392	8,705,796	

Note: Summary:

Average cost of repairs per lock (all)	$ 157,458
Average cost of repairs per lock (miter gates)	$ 108,822
Average cost for all accidents	$ 18,389
Average cost for miter gate accidents	$ 22,209

* Records pertaining to miter gate accidents were incomplete.

Table 3

Totals by River System

River	Number of Locks	All Accidents			Miter Gates Only		
		Number	Total Cost, $	Average Cost $/Lock	Number	Total Cost, $	Average Cost $/Lock
Mississippi	28	394	6,919,906	247,140	268	5,153,900	184,068
Ohio	20	168	3,731,430	186,572	80*	2,757,993*	137,900*
Illinois	8	21	860,250	107,531	9	421,450	52,681
Tennessee	8	32	484,465	60,558	6	45,553	5,694
Monongahela	6	23	405,940	67,657	10	211,576	35,263
Kanawha	3	33	144,905	48,302	12	82,861	27,620
Allegheny	3	4	14,674	4,891	*	*	*
Green	2	8	30,775	15,388	6	29,687	14,843
Cumberland	1	1	1,500	1,500	0	0	0
Kaskaskia	1	1	2,776	2,776	1	2,776	2,776
Total	80	685	12,596,621		392	8,705,796	

* Records pertaining to miter gate accidents were incomplete.

Table 4

Data by Lock in District Survey

District	River	Lock Name	All Accidents Total	All Accidents Cost, $	Miter Gates Only Total	Miter Gates Only Cost, $
ORH	Ohio	Belleville	5	48,639	2	13,078
		Gallipolis	52	1,747,811	33	1,494,327
		Greenup	4	6,107	2	1,620
		Meldahl	14	500,623	11	499,289
		Racine	2	1,247	2	1,247
		Willow Island	7	364,537	5	362,036
		River subtotal	84	2,668,964	55	2,371,597
	Kanawha	London	4	2,411	2	1,415
		Marmet	9	43,290	4	3,315
		Winfield	20	99,204	6	78,131
		River subtotal	33	144,905	12	82,861
		District total	117	2,813,869	67	2,454,458
ORL	Ohio	Lock 52	11	365,356	2	3,018
		Lock 53	4	5,668	0	0
		Cannelton	5	72,289	4	68,889
		Markland	5	5,158	3	3,962
		McAlpine	5	47,516	2	5,962
		Newburgh	5	139,286	2	111,198
		Smithland	11	105,850	7	94,455
		Uniontown	6	99,788	5	98,912
		River subtotal	52	840,911	25	386,396
	Green	Lock 1	2	26,320	2	26,320
		Lock 2	6	4,455	4	3,367
		River subtotal	8	30,775	6	29,687
		District total	60	871,686	31	416,083
ORN	Tennessee	Chickamauga	1	13,000	0	0
		Fort Loudoun	1	762	0	0
		Guntersville	8	33,000	0	0
		Kentucky	4	23,264	1	2,264
		Nickajack	2	1,189	0	0
		Pickwick	4	122,448	2	35,899
		Wheeler	5	31,430	2	5,390
		Wilson	7	259,372	1	2,000*
		River subtotal	32	484,465	6	45,553

(Continued)

* Accident on 1/20/82 causing $250,000 damage to upstream vertical lift gate was not counted.

Table 4 (Continued)

District	River	Lock Name	All Accidents Total	All Accidents Cost, $	Miter Gates Only Total	Miter Gates Only Cost, $
ORN (Continued)	Cumberland	Cheatham	1	1,500	0	0
		River subtotal	1	1,500	0	0
		District total	33	485,965	6	45,553
ORP	Ohio	Dashields	1	2,077	**	**
		Emsworth	11	47,643	**	**
		Hannibal	3	3,620	**	**
		Montgomery	10	74,323	**	**
		New Cumberland	4	90,567	**	**
		Pike Island	3	3,325	**	**
		River subtotal	32	221,555		
	Allegheny	Lock 2	1	3,635	**	**
		Lock 3	2	6,952	**	**
		Lock 5	1	4,087	**	**
		River subtotal	4	14,674		
	Monongahela	Lock 2	2	1,061	**	**
		Lock 3	6	14,449	6	14,449
		Lock 4	4	36,935	3	35,902
		Lock 7	7	90,820	**	**
		Lock 8	2	5,950	**	**
		Maxwell	2	256,725	1	161,225
		River subtotal	23	405,940	10	211,576
		District total	59	642,169	**	**
NCR	Upper Mississippi	Lock 11	7	151,900	5	129,400
		Lock 12	7	306,000	6	256,000
		Lock 13	2	70,000	2	70,000
		Lock 14	10	82,400	7	76,100
		Lock 15	14	517,300	5	203,500
		Lock 16	3	7,200	2	4,700
		Lock 17	10	964,500	8	936,500
		Lock 18	19	188,000	12	179,700
		Lock 19	12	76,855	2	8,300
		Lock 20	7	10,400	4	7,000
		Lock 21	8	684,527	5	672,800
		Lock 22	25	915,350	18	475,600
		River subtotal	124	3,974,432	76	3,019,600

(Continued)

** Records pertaining to miter gate accidents were incomplete.

Table 4 (Concluded)

District	River	Lock Name	All Accidents Total	All Accidents Cost, $	Miter Gates Only Total	Miter Gates Only Cost, $
NCR (Continued)	Illinois	Brandon Road	1	3,300	0	0
		Dresdon Island	1	1,000	1	1,000
		La Grange	4	50,900	1	3,400
		Lockport	3	19,850	2	2,850
		Marseilles	2	315,000	0	0
		Peoria	4	436,500	2	402,500
		Starved Rock	5	24,700	3	11,700
		T. J. O'Brien	1	9,000	0	0
		River subtotal	21	860,250	9	421,450
		District total	145	4,834,682	85	3,441,050
LMS	Upper Mississippi	Lock 24	26	694,027	18	681,631
		Lock 25	29	708,018	15	672,331
		Lock 26	21	327,529	9	46,598
		Lock 27	21	95,228	16	80,060
		River subtotal	97	1,824,802	58	1,480,620
	Kaskaskia	Kaskaskia	1	2,776	1	2,776
		River subtotal	1	2,776	1	2,776
		District total	98	,827,578	59	1,483,396
NCS	Upper Mississippi	Lock 1	2	769	1	504
		Lock 2	7	11,518	4	5,442
		Lock 3	26	109,818	14	30,806
		Lock 4	15	91,865	12	14,901
		Lock 5	16	120,705	7	12,630
		Lock 5A	12	41,380	11	25,551
		Lock 6	18	19,901	15	16,113
		Lock 7	13	28,469	13	28,469
		Lock 8	21	44,821	19	30,580
		Lock 9	30	566,641	28	466,956
		Lock 10	12	83,355	10	21,728
		Upper St. Anthony Falls	1	1,430	0	0
		River subtotal	173	1,120,672	134	653,680
		District total	173	1,120,672	134	653,680

Table 5

Locks with the Most Number of Accidents

Lock Name	District	All Accidents		Miter Gates Only	
		Number	Number per Year	Number	Number per Year
Gallipolis	ORH	52	4.7	33	3.0
Lock 9	NCS	30	3.0	28	2.8
Lock 8	NCS	21	2.1	19	1.9
Lock 24	LMS	26	3.7	18	2.6
Lock 22	NCR	25	2.5	18	1.8
Lock 27	LMS	21	3.0	16	2.3
Lock 25	LMS	29	4.1	15	2.1
Lock 6	NCS	18	1.8	15	1.5
Lock 3	NCS	26	2.6	14	1.4
Lock 7	NCS	13	1.3	13	1.3

Table 6

Locks with the Highest Average Cost Per Accident

Lock Name	District	Cost, $/Accident	
		All Accidents	Miter Gates Only
Lock 21	NCR	85,566	134,560
Lock 17	NCR	96,450	117,063
Willow Island	ORH	52,076	72,407
Meldahl	ORH	35,759	45,390
Gallipolis	ORH	33,612	45,283
Lock 25	LMS	24,410	44,822
Lock 12	NCR	43,714	42,667
Lock 15	NCR	36,950	40,700
Lock 24	LMS	26,693	37,868
Lock 22	NCR	36,614	26,422

Note: Locks must have minimum of five accidents to miter gates.

Table 7

Locks with the Highest Average Annual Damages

Lock Name	District	Average Annual Damages, $
Gallipolis	ORH	158,892
Lock 25	LMS	101,145
Lock 24	LMS	99,147
Lock 17	NCR	96,450
Lock 22	NCR	91,350
Lock 21	NCR	68,453
Lock 9	NCS	56,664
Lock 15	NCR	51,730
Lock 26	LMS	46,790
Lock 52	ORL	45,670
Meldahl	ORH	45,511

Table 8

Locks with the Highest Average Annual Damages to Miter Gates

Lock Name	District	Average Annual Damages, $
Gallipolis	ORH	135,849
Lock 24	LMS	97,376
Lock 25	LMS	96,047
Lock 17	NCR	95,650
Lock 21	NCR	67,280
Lock 22	NCR	47,560
Lock 9	NCS	46,696
Meldahl	ORH	45,390
Peoria	NCR	40,250
Willow Island	ORH	32,912

Table 9

Locks with the Highest Total Damages

Lock Name	District	Total, $
Gallipolis	ORH	1,747,811
Lock 17	NCR	964,500
Lock 22	NCR	915,350
Lock 25	LMS	708,018
Lock 24	LMS	694,027
Lock 21	NCR	684,527
Lock 9	NCS	566,641
Lock 15	NCR	517,300
Meldahl	ORH	500,623
Peoria	NCR	436,500

Table 10

Catastrophic Accidents

Lock Name	Date	Cost of Repairs or Damages, $	Struck Miter Gate
		Huntington	
Gallipolis	04/01/77	202,868	Yes
	05/01/77	112,099	Yes
	12/08/77	78,190	No
	01/10/79	66,815	No
	06/13/80	64,622	Yes
	03/17/81	85,586	Yes
	04/02/84	382,931	Yes
	04/27/84	280,364	Yes
	08/04/85	209,285	Yes
Meldahl	07/11/79	400,000	Yes
Willow Island	03/31/84	344,431	Yes
Winfield	04/01/85	76,012	Yes
		Louisville	
Lock 52	12/17/81	294,252	No
Newburgh	03/22/83	61,465	Yes
Smithland	09/29/86	71,600	Yes
Uniontown	01/03/79	56,558	Yes
		Nashville	
Pickwick	03/14/87	75,000	No
Wilson	01/20/82	250,000	No
		Pittsburgh	
Maxwell	01/23/82	95,500	No
	01/23/82	161,225	Yes
		Rock Island	
Lock 11	12/06/81	70,000	Yes
Lock 12	07/30/79	85,000	Yes
	08/21/79	50,000	Yes
	04/05/81	50,000	Yes
	04/16/81	50,000	Yes
	06/25/84	50,000	No
Lock 13	04/22/82	50,000	Yes
Lock 14	11/04/82	65,000	Yes
Lock 15	05/09/79	150,000	No
	05/03/81	150,000	No
	08/07/85	125,000	Yes

(Continued)

Table 10 (Concluded)

Lock Name	Date	Cost of Repairs or Damages, $	Struck Miter Gate
	Rock Island (Continued)		
Lock 17	08/12/80	210,000	Yes
	11/06/80	160,000	Yes
	03/27/84	100,000	Yes
	04/02/85	450,000	Yes
Lock 18	04/07/80	75,000	Yes
	09/11/80	55,000	Yes
Lock 21	08/17/79	61,300	Yes
	12/02/80	160,000	Yes
	06/28/82	200,000	Yes
	09/27/83	250,000	Yes
Lock 22	08/29/79	368,300	No
	09/19/79	65,000	Yes
	08/09/81	100,000	Yes
	05/26/82	50,000	Yes
	10/14/82	150,000	Yes
	08/25/84	75,000	Yes
Marseilles	05/24/84	300,000	No
Peoria	11/24/81	400,000	Yes
	St. Louis		
Lock 24	07/26/80	208,565	Yes
	03/22/84	197,295	Yes
	05/27/86	225,504	Yes
Lock 25	08/24/85	600,378	Yes
Lock 26	08/23/83	55,470	No
	01/29/85	136,215	No
Lock 27	07/21/84	53,941	Yes
	St. Paul		
Lock 4	08/31/85	76,273	No
Lock 5	07/30/82	52,134	No
Lock 9	07/04/78	99,237	No
	11/23/81	419,655	Yes
Lock 10	10/10/80	59,663	No

Table 11

Data Items Found in PMS Report 18

Vessel name
Direction
Number of loaded barges
Cargo tonnage
Arrival: month/day/hour/minute
Wait time
Lockage time
Number of cuts for lockage
Processing time
Stall code
Duration of stall
Transit time
Exceptional performance: Time that vessel or lock processing time is better or poorer than average for approach, entry, exit, or chambering

Table 12

Miter Gate Accidents

Lock 24, Mississippi River

Date	Amount of Damage, $	PMS Report Available
April 6, 1980	1,179	No
May 28, 1980	2,182	Yes
July 26, 1980	208,565	Yes
September 7, 1981	436	Yes
October 12, 1981	5,826	Yes
March 20, 1982	2,154	Yes
March 23, 1982	667	Yes
April 9, 1982	1,089	Yes
July 5, 1982	7,531	Yes
November 5, 1983	13,241	No
November 14, 1983	1,000	No
December 16, 1983	5,512	No
March 22, 1984	197,295	Yes
September 24, 1984	2,387	Yes
November 24, 1984	5,597	No
April 15, 1985	426	Yes
May 18, 1986	680	Yes
May 27, 1986	225,504	Yes

Table 13

Miter Gate Accidents

Lock 25, Mississippi River

Date	Amount of Damage, $	PMS Report Available
June 16, 1980	542	Yes
October 21, 1980	573	No
June 10, 1981	1,073	Yes
August 23, 1981	718	No
November 12, 1981	623	Yes
June 29, 1982	20,935	Yes
February 10, 1983	669	No
March 20, 1983	1,596	No
May 27, 1983	1,250	Yes
March 12, 1984	7,291	No
June 29, 1984	10,130	Yes
October 13, 1984	22,614	Yes
July 3, 1985	1,012	Yes
August 24, 1985	600,378	Yes

Table 14

Towboat Delays Before and After Selected Miter Gate Accidents

Lock	Month	Damage Estimate $	Average Delay in Hours			
			30 Vessels Before Accident	Next Vessels After Accident		
				5	10	20
Lock 24	7/80	208,565	2.43	5.30	4.34	5.56
Lock 24	9/84	2,387	3.26	2.28	2.34	2.24
Lock 24	5/86	680	2.59	1.77	1.70	2.14
Lock 25	5/83	1,250	3.21	4.80	2.82	3.10
Lock 25	7/85	1,012	14.08	66.30	40.03	30.20

APPENDIX A: BARRIER DESIGN

Note: All elevations (el) cited in this appendix are in feet referred to the National Geodetic Vertical Datum.

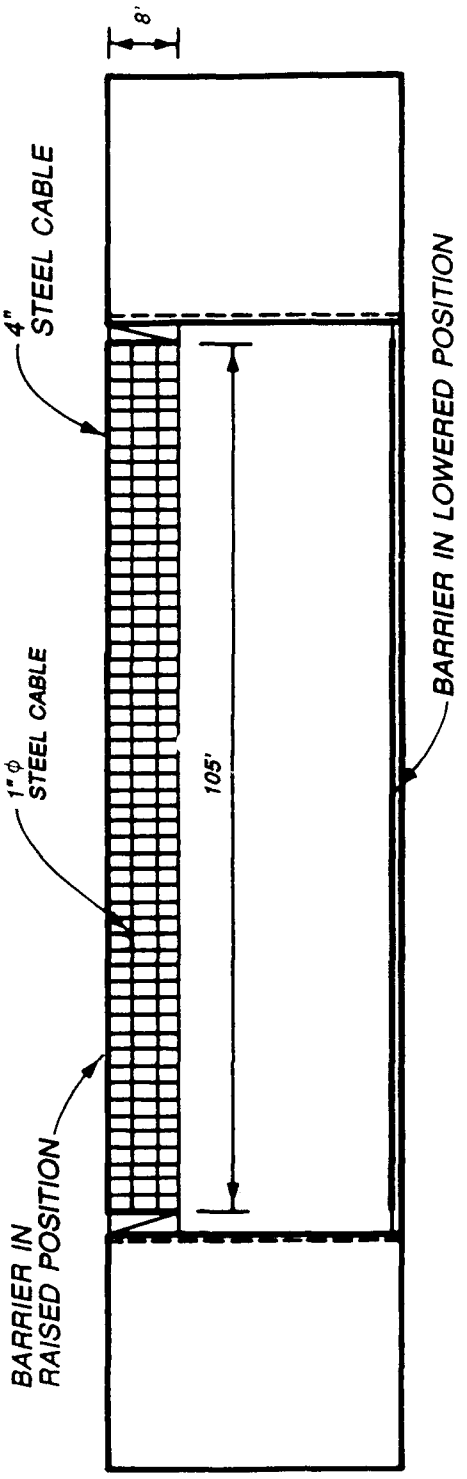


Figure A1. Cross section of lock and barrier

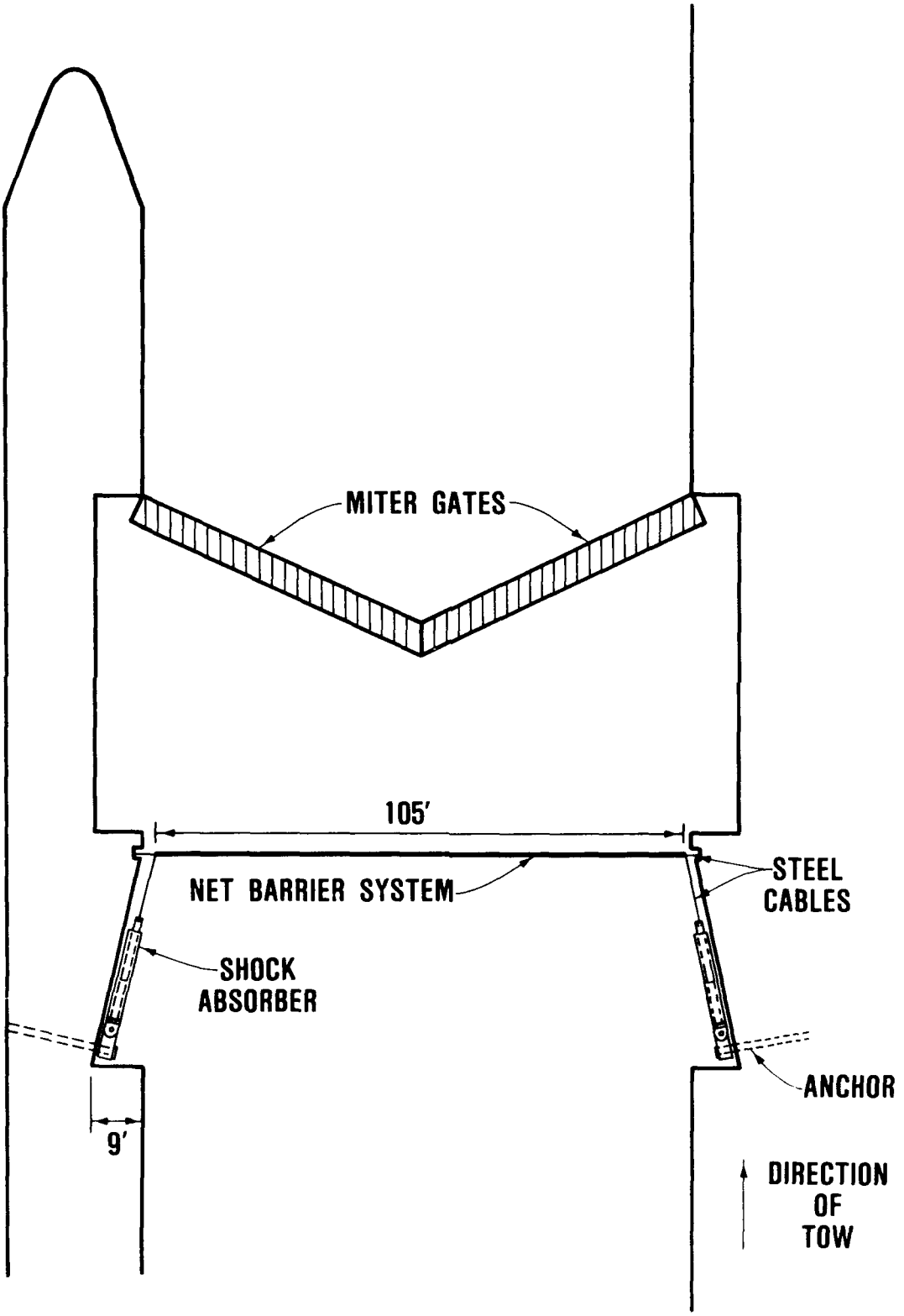


Figure A2. Plan view of barrier system

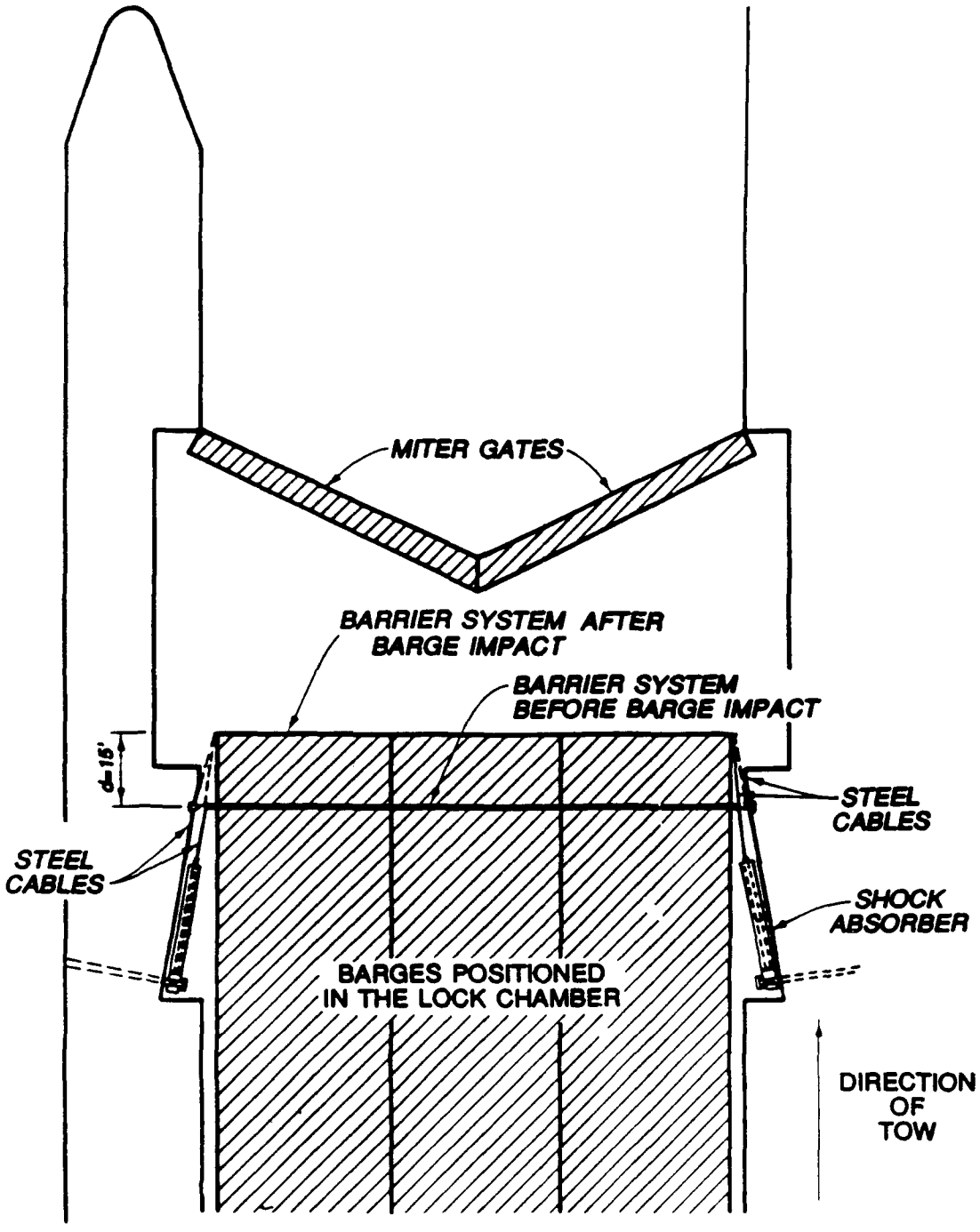


Figure A3. Plan view of the tow arrester system

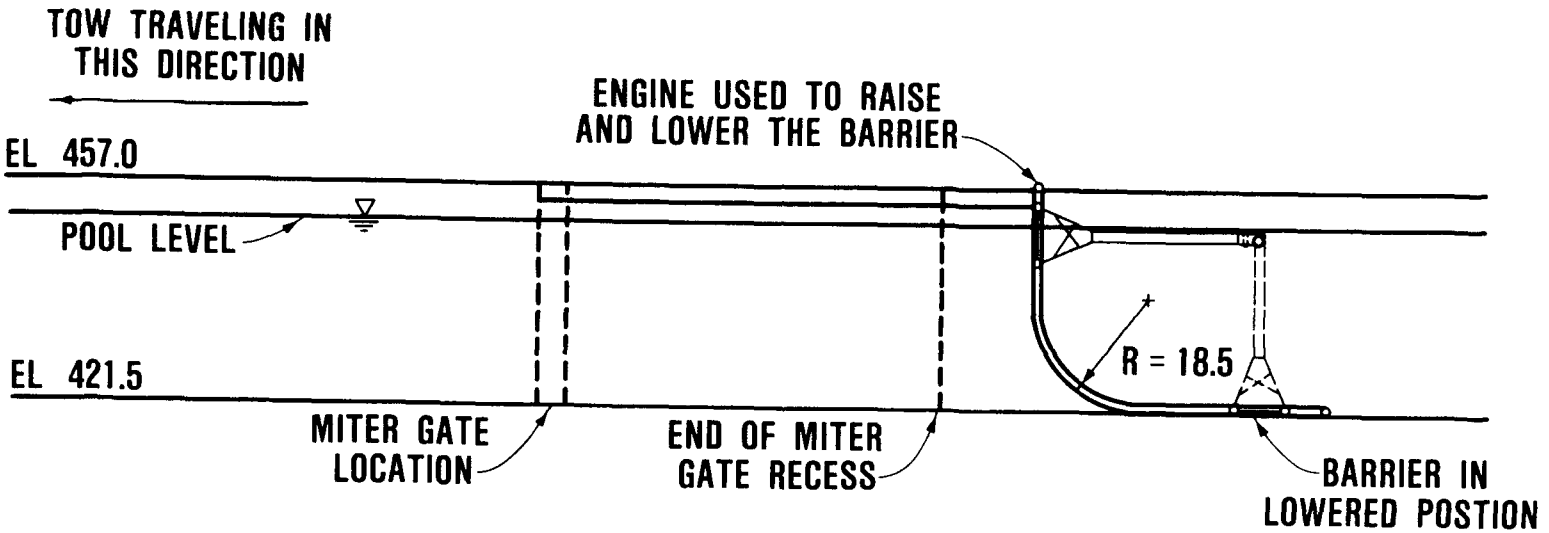


Figure A4. Left side elevation view

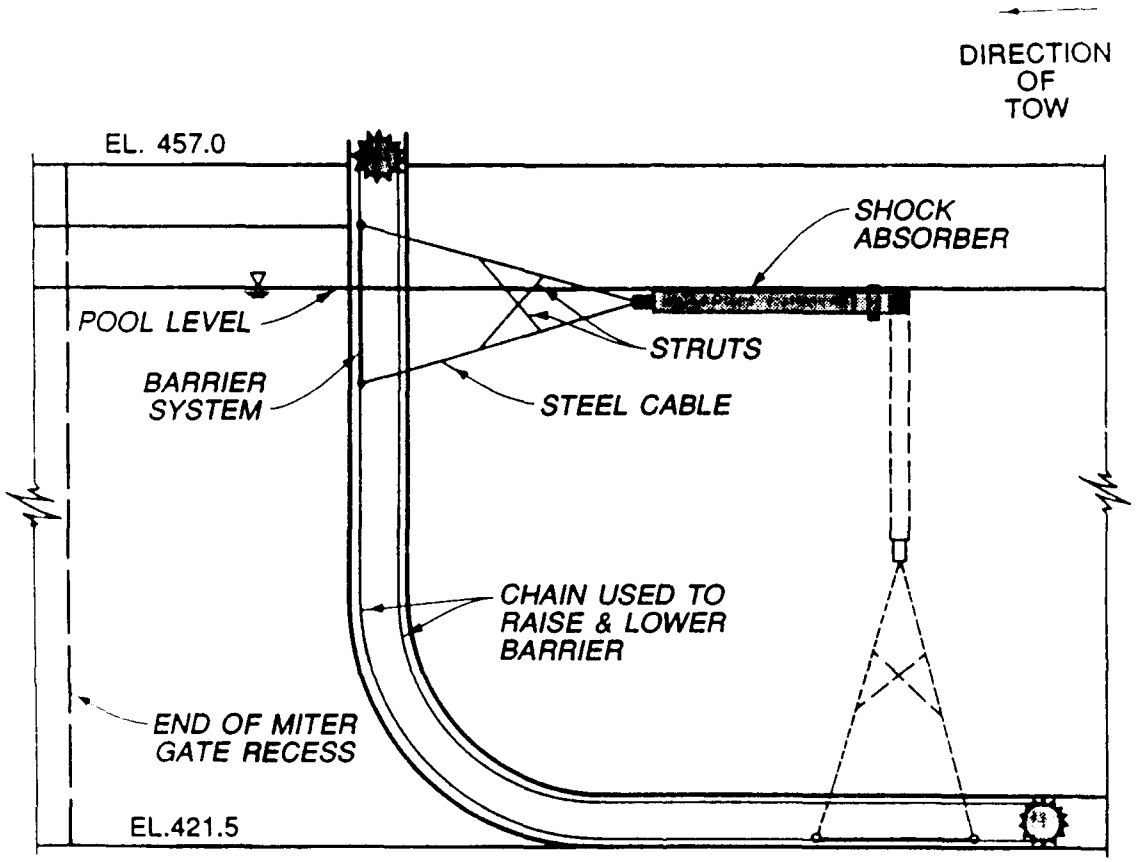


Figure A5. Side view of the raising and lowering mechanism

APPENDIX B: PMS LOCK VOLUME DATA

Table B1

Lock Volume Data

River	Lock	Months	July-September 1983 Lockages	Barges	Tonnage
		St. Louis			
Mississippi	24		2124	15796	13145
	25		2081	15825	13182
	26		2698	19193	16707
	Auxiliary Lock 26		1834	4679	4397
	27		2201	23926	21321
	Auxiliary Lock 27		903	1825	1466
Kaskaskia	Kaskaskia		371	970	728
		Rock Island			
Mississippi	11		1230	10044	8320
	12		1327	10822	8996
	13		1355	10835	8997
	14		1811	13153	10602
	Auxiliary Lock 14		0	0	0
	15		1961	12705	10623
	Auxiliary Lock 15		357	320	219
	16		2053	13813	11627
	17		2057	14484	12162
	18		2003	14778	12402
	19		1221	15078	12600
	Auxiliary Lock 19		0	0	0
	20		2134	15248	12718
	21		2104	15363	12836
	22		2087	15453	12997
Illinois	T. J. O'Brien		763	1953	1765
	Lockport		1036	5056	4611
	Brandon		1063	5141	4722
	Dresden Island		978	5453	5226
	Marseilles		985	5390	5445
	Starved Rock		1021	5802	5869
	Peoria		1069	7553	7516
	La Grange		1072	7542	7719
		St. Paul			
Mississippi	1		657	1070	799
	Auxiliary Lock 1	2	3	2	0
	2		1056	8583	6536
	Auxiliary Lock 2		0	0	0
	3		906	7914	6058

(Continued)

Table B1 (Continued)

River	Lock	Months	July-September 1983 Lockages	Barges	Tonnage
Mississippi (Continued)	4		910	8255	6407
	5		928	8209	6446
	5A		943	8181	6409
	6		972	8902	6969
	7		987	8907	7005
	8		1004	8987	7136
	9		996	9161	7464
	10		1185	10125	8168
	Upper St. Anthony Falls		492	693	511
	Lower St. Anthony Falls		610	1071	781
	Huntington				
Kanawha	Winfield 1		1531	2385	1906
	Winfield 2		1514	2705	1480
	Marmet 1		995	1646	1239
	Marmet 2		659	1215	517
	London 1		129	183	88
	London 2		446	677	415
Ohio	Belleville		678	7051	7042
	Belleville Auxiliary		98	243	101
	Racine		785	7925	7390
	Racine Auxiliary		128	352	146
	Gallipolis		1167	6740	6539
	Gallipolis Auxiliary		322	1046	864
	Greenup		321	3220	2825
	Greenup Auxiliary		1065	6840	5863
	Meldahl		924	9777	9148
	Meldahl Auxiliary		64	168	87
	Willow Island		686	6773	6490
	Willow Island Auxiliary		205	500	205
	Louisville				
Green	1		673	2494	2017
	2		546	2060	1540
Ohio	Markland		833	8397	8126
	Markland Auxiliary		170	877	764
	McAlpine		681	5315	5614
	McAlpine Auxiliary	10	719	3975	3994
	Cannelton		1008	9846	10096

(Continued)

Table B1 (Continued)

River	Lock	Months	July-September 1983 Lockages	Barges	Tonnage
		Louisville (Continued)			
Ohio (Continued)	Cannelton Auxiliary		66	151	70
	Newburgh		1171	10931	10462
	Newburgh Auxiliary		172	291	176
	Uniontown		1117	12067	11422
	Uniontown Auxiliary		118	209	147
	Smithland		703	6950	8021
	Smithland Auxiliary		760	7633	5087
	52		937	12348	11640
	Auxiliary Lock 52		792	3996	3688
		Nashville			
Cumberland	Barkley		163	1227	543
	Cheatham		199	1105	845
	Cordell Hull		0	0	0
	Old Hickory		85	106	75
Tennessee	Melton Hill		2	0	0
	Kentucky		1362	8123	6691
	Pickwick		675	4758	3768
	Pickwick Auxiliary				
	Wilson		424	2345	1942
	Wilson Auxiliary	1	61	84	60
	Wheeler		324	2176	1794
	Wheeler Auxiliary		23	130	106
	Guntersville		316	2036	1619
	Guntersville Auxiliary		3	1	0
	Nickajack		367	2111	1546
	Chickamauga		248	646	564
	Watts Bar		128	360	347
	Fort Loudoun		68	124	122
		Pittsburgh			
Allegheny	2		950	1612	566
	3		1033	1652	581
	4		947	1392	368
	5		711	1232	260
	6		603	1237	260
	7		85	146	31
	8		267	0	0
	9		0	0	0

(Continued)

Table B1 (Continued)

River	Lock	July-September 1983 Months	Lockages	Barges	Tonnage
	Pittsburgh (Continued)				
Monongahela	2		953	5138	3124
	Auxiliary Lock 2		675	456	145
	3		1461	7355	3884
	Auxiliary Lock 3		802	384	141
	4		1208	6383	3239
	Auxiliary Lock 4		469	117	29
	Maxwell		771	3059	759
	Maxwell Auxiliary		795	2942	2298
	7		1874	4469	2193
	8		1600	3927	2947
	Morgantown		240	477	225
	Hildebrand		202	96	50
	Opekiska		128	31	14
Ohio	Emsworth		1091	4298	2810
	Emsworth Auxiliary		629	1322	782
	Dashields		966	5444	3475
	Dashields Auxiliary		631	226	98
	Montgomery		1017	5611	3906
	Montgomery Auxiliary		510	156	54
	New Cumberland		567	4839	4302
	New Cumberland Auxiliary		540	766	382
	Pike Island		660	5859	5499
	Pike Island Auxiliary		552	713	351
	Hannibal		368	3677	3235
	Hannibal Auxiliary		590	3629	3160

(Continued)

Table B1 (Continued)

River	Lock	October-December 1984 Months	Lockages	Barges	Tonnage
		St. Louis			
Mississippi	24		1449	9281	9391
	25		1434	9287	9500
	26		2501	16984	16449
	Auxiliary Lock 26		1417	2958	2852
	27		2142	20048	19612
	Auxiliary Lock 27		688	1459	1203
Kaskaskia	Kaskaskia		459	1408	907
		Rock Island			
Mississippi	11		677	4337	4747
	12		759	4874	5300
	13		770	4912	5343
	14		1071	6161	6271
	Auxiliary Lock 14				
	15		1107	5991	6292
	Auxiliary Lock 15		255	243	150
	16		1294	7127	7276
	17		1186	7259	7549
	18		1228	7572	7842
	19		758	8255	8523
	Auxiliary Lock 19				
	20		1358	8482	8671
	21		1384	8628	8791
	22		1380	8821	9051
Illinois	T. J. O'Brien		693	1735	1556
	Lockport		1133	5014	4563
	Brandon		1242	5097	4668
	Dresden Island		1121	5185	5037
	Marseilles		1161	5312	5342
	Starved Rock		1230	5962	5864
	Peoria		1404	8526	8065
	La Grange		1224	9388	8896
		St. Paul			
Mississippi	1	2	428	741	550
	Auxiliary Lock 1				
	2		669	3700	3583
	Auxiliary Lock 2				
	3	2	519	3135	3211
	4		555	3365	3505
	5	2	561	3365	3509

(Continued)

Table B1 (Continued)

River	Lock	October-December 1984 Months	Lockages	Barges	Tonnage
	St. Paul (Continued)				
Mississippi (Continued)	5A	2	526	3352	3467
	6		582	3848	3956
	7		626	3865	3961
	8		597	4009	4153
	9		571	3850	4241
	10		639	4348	4694
	Upper St. Anthony Falls	2	297	380	315
	Lower St. Anthony Falls	2	430	742	562
	Huntington				
Kanawha	Winfield 1		2496	4151	2808
	Winfield 2		244	433	158
	Marmet 1		883	1352	900
	Marmet 2		596	824	352
	London 1		358	357	245
	London 2		117	118	80
Ohio	Belleville		685	7483	7012
	Belleville Auxiliary		101	310	134
	Racine		755	8087	7355
	Racine Auxiliary		141	438	192
	Gallipolis		1348	7622	7295
	Gallipolis Auxiliary		125	157	97
	Greenup		1084	10063	9332
	Greenup Auxiliary		240	273	151
	Meldahl		968	10249	9915
	Meldahl Auxiliary		100	230	133
	Willow Island		666	7046	6340
	Willow Island Auxiliary		192	509	233
	Louisville				
Green	1		659	2594	2031
	2		414	1772	1328
Ohio	Markland		1050	10181	10428
	Markland Auxiliary		72	124	67
	McAlpine		1308	10650	11365
	McAlpine Auxiliary				
	Cannelton		1118	11276	12030

(Continued)

Table B1 (Continued)

River	Lock	October–December 1984 Months	Lockages	Barges	Tonnage
	Louisville (Concinued)				
Ohio (Continued)	Cannelton Auxiliary		79	206	146
	Newburgh		1368	13642	13302
	Newburgh Auxiliary		274	544	305
	Uniontown		1481	16350	15971
	Uniontown Auxiliary		125	247	135
	Smithland		931	9424	11686
	Smithland Auxiliary		897	8982	5631
	52		339	20371	18905
	Auxiliary Lock 52	1	215	607	622
	Nashville				
Cumberland	Barkley		210	1380	600
	Cheatham		199	1089	822
	Cordell Hull		28	38	27
	Old Hickory		91	103	95
Tennessee	Melton Hill		0	0	0
	Kentucky		1359	8042	6553
	Pickwick		439	3487	2839
	Pickwick Auxiliary		292	1713	1298
	Wilson		411	2034	1734
	Wilson Auxiliary				
	Wheeler		339	1987	1664
	Wheeler Auxiliary		6	1	2
	Guntersville		337	1881	1503
	Guntersville Auxiliary		4	0	0
	Nickajack		375	2129	1552
	Chickamauga		276	585	467
	Watts Bar		175	300	276
	Fort Loudoun		103	138	133
	Pittsburgh				
Allegheny	2		759	1682	628
	3		820	1740	646
	4		699	1828	514
	5		416	1534	326
	6		412	1469	312
	7		106	169	37
	8		220	192	186
	9	1	10	0	0

(Continued)

Table B1 (Continued)

River	Lock	October-December 1984 Months	Lockages	Barges	Tonnage
	Pittsburgh (Continued)				
Monongahela	2		760	4028	2578
	Auxiliary Lock 2		361	362	119
	3		1033	5142	2823
	Auxiliary Lock 3		334	243	92
	4		963	5118	2694
	Auxiliary Lock 4		142	129	31
	Maxwell		441	2471	578
	Maxwell Auxiliary		385	2290	1936
	7		1523	3757	1910
	8		1332	3281	1685
	Morgantown		117	431	200
	Hildebrand		39	95	50
	Opekiska		17	10	5
Ohio	Emsworth		968	4984	3240
	Emsworth Auxiliary		474	375	140
	Dashields		962	5531	3556
	Dashields Auxiliary		384	266	100
	Montgomery		818	4398	2930
	Montgomery Auxiliary		817	1160	790
	New Cumberland		481	4733	4096
	New Cumberland Auxiliary		367	737	390
	Pike Island		590	6406	5366
	Pike Island Auxiliary		311	708	403
	Hannibal		583	6590	5828
	Hannibal Auxiliary		145	339	216

(Continued)

Table B1 (Continued)

River	Lock	Months	April–June 1985 Lockages	Barges	Tonnage
		St. Louis			
Mississippi	24		1338	9617	9094
	25		1317	9620	9149
	26		2399	15922	15376
	Auxiliary Lock 26		911	1474	1358
	27		2350	19230	18701
	Auxiliary Lock 27		0	0	0
Kaskakia	Kaskaskia		568	1589	1084
		Rock Island			
Mississippi	11		809	5717	5516
	12		857	6287	609
	13		873	6307	6113
	14		1234	7806	7232
	Auxiliary Lock 14	2	3	0	0
	15		1275	7445	7209
	Auxiliary Lock 15		148	115	34
	16		1238	8063	7704
	17		1236	8475	8158
	18		1201	8725	8416
	19		794	9023	8598
	Auxiliary Lock 19				
	20		1363	9104	8627
	21		1286	9072	8650
	22		1289	9170	8789
Illinois	T. J. O'Brien		752	1824	1632
	Lockport		1076	4697	4089
	Brandon		1160	4777	4233
	Dresdon Island		1037	5183	4864
	Marseilles		1025	5326	5212
	Starved Rock		1097	5798	5634
	Peoria		668	7411	7159
	La Grange		518	7105	7151
		St. Paul			
Mississippi	1		572	835	618
	Auxiliary Lock 1				
	2		836	5628	4738
	Auxiliary Lock 2				
	3		657	4839	4178
	4		660	5060	5369
	5		690	[illegible]	4345

(Continued)

Table B1 (Continued)

River	Lock	April–June 1985 Months	Lockages	Barges	Tonnage
		St. Paul (Continued)			
Mississippi (Continued)	5A	2	823	4961	4336
	6		695	5273	4660
	7		693	5284	4666
	8		714	5442	4858
	9		696	5379	5211
	10		757	5699	5393
	Upper St. Anthony Falls		424	515	399
	Lower St. Anthony Falls		550	837	623
		Huntington			
Kanawha	Winfield 1		2885	4225	3184
	Winfield 2		964	1531	923
	Marmet 1		1497	2229	1553
	Marmet 2		651	968	465
	London 1	2	155	156	130
	London 2		647	726	494
Ohio	Belleville		821	9349	8765
	Belleville Auxiliary		103	330	175
	Racine		886	10031	9071
	Racine Auxiliary		116	323	166
	Gallipolis		1548	8770	8690
	Gallipolis Auxiliary		118	158	85
	Greenup		1164	10823	10054
	Greenup Auxiliary		94	120	49
	Meldahl		979	10695	10184
	Meldahl Auxiliary		108	313	220
	Willow Island		796	8847	8145
	Willow Island Auxiliary		193	596	251
		Louisville			
Green	1		814	3491	2799
	2		648	2481	1852
Ohio	Markland		993	9428	10044
	Markland Auxiliary		120	645	684
	McAlpine		1301	10724	12026
	McAlpine Auxiliary				
	Cannelton		1194	11793	12620

(Continued)

Table B1 (Continued)

River	Lock	April–June 1985 Months	Lockages	Barges	Tonnage
	Louisville (Continued)				
Ohio (Continued)	Cannelton Auxiliary		31	28	6
	Newburgh		1447	14405	14371
	Newburgh Auxiliary		238	504	239
	Uniontown		1493	15993	15841
	Uniontown Auxiliary		105	199	131
	Smithland		922	9052	10700
	Smithland Auxiliary		876	8939	6739
	52		184	20703	19611
	Auxiliary Lock 52		143	382	315
	Nashville				
Cumberland	Barkley		217	1545	840
	Cheatham		246	1480	1116
	Cordell Hull		39	80	55
	Old Hickory		99	130	90
Tennessee	Melton Hill		0	0	1
	Kentucky		1351	8057	6598
	Pickwick		472	3828	3058
	Pickwick Auxiliary	2	267	1765	1397
	Wilson		450	2372	2101
	Wilson Auxiliary				
	Wheeler		384	2262	1972
	Wheeler Auxiliary		6	1	1
	Guntersville		306	1875	1559
	Guntersville Auxiliary		2	0	0
	Nickajack		374	1985	1515
	Chickamauga		192	579	453
	Watts Bar		100	288	253
	Fort Loudoun		86	153	144
	Pittsburgh				
Allegheny	2		646	1629	609
	3		667	1644	622
	4		670	1896	580
	5		439	1631	344
	6		449	1578	336
	7		29	57	14
	8		196	183	141
	9	2	0	0	0

(Continued)

Table B1 (Continued)

River	Lock	April–June 1985 Months	Lockages	Barges	Tonnage
	Pittsburgh (Continued)				
Monongahela	2		1165	7036	4447
	Auxiliary Lock 2		485	516	225
	3		1619	8107	4393
	Auxiliary Lock 3		632	476	226
	4		1397	7483	3957
	Auxiliary Lock 4		279	390	185
	Maxwell		676	3771	1039
	Maxwell Auxiliary		632	3682	2880
	7		2063	5023	2659
	8		1722	4172	2239
	Morgantown		219	804	400
	Hildebrand		105	370	198
	Opekiska		39	87	43
Ohio	Emsworth		1327	7388	4936
	Emsworth Auxiliary		578	431	191
	Dashields		1112	6958	4597
	Dashields Auxiliary		807	1142	719
	Montgomery		1383	7856	5502
	Montgomery Auxiliary		226	93	36
	New Cumberland		669	7031	5774
	New Cumberland Auxiliary		461	1458	823
	Pike Island		807	8757	7540
	Pike Island Auxiliary		329	691	279
	Hannibal		715	8429	7883
	Hannibal Auxiliary		125	378	165

(Continued)

Table B1 (Continued)

River	Lock	Months	July-September 1985 Lockages	Barges	Tonnage
		St. Louis			
Mississippi	24		1144	8160	8611
	25		1075	8128	8617
	26		13962	2125	14544
	Auxiliary Lock 26		867	1214	1102
	27		2215	17498	18011
	Auxiliary Lock 27		0	0	0
Kaskaskia	Kaskaskia		404	943	672
		Rock Island			
Mississippi	11		636	5132	5280
	12		658	5396	5612
	13		675	5384	5630
	14		976	6368	6493
	Auxiliary Lock 14		6	0	0
	15		1086	6137	6537
	Auxiliary Lock 15		184	141	55
	16		1013	6634	7025
	17		913	6881	7350
	18		906	7014	7482
	19		657	7277	7773
	Auxiliary Lock 19				
	20		1056	7397	7926
	21		1022	7549	8098
	22		1072	7781	8309
Illinois	T. J. O'Brien		704	1755	1551
	Lockport		1083	4867	4172
	Brandon		1132	4945	4355
	Dresden Island		1020	5275	4921
	Marseilles		986	5266	5128
	Starved Rock		1008	5591	5462
	Peoria		1169	6900	6842
	La Grange		1106	6608	6882
		St. Paul			
Mississippi	1		553	884	678
	Auxiliary Lock 1				
	2		759	5574	4832
	Auxiliary Lock 2				
	3		599	4801	4352
	4		595	4914	4473
	5		613	4876	4447

(Continued)

Table B1 (Continued)

River	Lock	Months	July-September 1985 Lockages	Barges	Tonnage
	St. Paul (Continued)				
Mississippi (Continued)	5A		780	4885	4472
	6		622	5047	4757
	7		644	5044	4743
	8		573	5062	4897
	9		549	4922	5011
	10		599	5177	5187
	Upper St. Anthony Falls		389	577	462
	Lower St. Anthony Falls		515	879	677
	Huntington				
Kanawha	Winfield 1		2145	3158	2428
	Winfield 2		2039	3107	1832
	Marmet 1		1202	1819	1380
	Marmet 2		1092	1754	890
	London 1	2	273	283	116
	London 2		680	804	656
Ohio	Belleville		691	7682	7532
	Belleville Auxiliary		122	343	170
	Racine		771	8344	7815
	Racine Auxiliary		111	289	157
	Gallipolis		1310	7438	7362
	Gallipolis Auxiliary	2	289	891	900
	Greenup		1122	11721	10761
	Greenup Auxiliary		234	426	249
	Meldahl		1094	11624	10888
	Meldahl Auxiliary	2	68	176	135
	Willow Island		675	7316	6916
	Willow Island Auxiliary		182	449	203
	Louisville				
Green	1		838	3118	2383
	2		585	2225	1656
Ohio	Markland		354	3739	3754
	Markland Auxiliary		974	6417	6569
	McAlpine		1142	10025	10547
	McAlpine Auxiliary	2	213	1213	1323
	Cannelton		1228	12415	12301

(Continued)

Table B1 (Continued)

River	Lock	July-September 1985 Months	Lockages	Barges	Tonnage
	Louisville (Continued)				
Ohio (Continued)	Cannelton Auxiliary	2	46	89	48
	Newburgh		1322	13831	13476
	Newburgh Auxiliary		229	404	181
	Uniontown		1365	15245	14507
	Uniontown Auxiliary		136	237	120
	Smithland		850	8551	10298
	Smithland Auxiliary		903	9181	6122
	52		1404	17751	16632
	Auxiliary Lock 52		966	2546	2410
	Nashville				
Cumberland	Barkley		198	1415	709
	Cheatham		293	1456	1169
	Cordell Hull		26	47	34
	Old Hickory		98	136	103
Tennessee	Melton Hill		1	0	0
	Kentucky		1309	7681	6519
	Pickwick		737	5861	4554
	Pickwick Auxiliary				
	Wilson		469	2569	2147
	Wilson Auxiliary				
	Wheeler		409	2456	2020
	Wheeler Auxiliary		8	3	0
	Guntersville		348	2239	1819
	Guntersville Auxiliary				
	Nickajack		392	2192	1606
	Chickamauga		219	606	463
	Watts Bar		116	275	261
	Fort Loudoun		76	127	125
	Pittsburgh				
Allegheny	2		685	1832	699
	3		704	1838	700
	4		644	2001	561
	5		442	1748	380
	6		438	1585	339
	7		59	127	34
	8		366	357	282
	9		2	0	0

(Continued)

Table B1 (Continued)

River	Lock	July-September 1985 Months	Lockages	Barges	Tonnage
	Pittsburgh (Continued)				
Monongahela	2		980	6243	3885
	Auxiliary Lock 2		485	509	185
	3		1424	7231	3938
	Auxiliary Lock 3		784	1626	860
	4		1139	5970	3339
	Auxiliary Lock 4		637	1828	924
	Maxwell		654	3698	1005
	Maxwell Auxiliary		625	3714	3013
	7		2212	5742	3073
	8		1924	4899	2672
	Morgantown		292	1050	540
	Hildebrand		184	630	337
	Opekiska		103	203	104
Ohio	Emsworth		1232	6922	4454
	Emsworth Auxiliary		654	431	160
	Dashields		1142	7416	4762
	Dashields Auxiliary		487	321	132
	Montgomery		1193	7699	5143
	Montgomery Auxiliary		344	211	83
	New Cumberland		628	6351	5221
	New Cumberland Auxiliary		443	908	486
	Pike Island		661	6799	6129
	Pike Island Auxiliary		314	622	305
	Hannibal		687	7453	6869
	Hannibal Auxiliary		118	258	94

(Continued)

Table B1 (Continued)

River	Lock	Months	October–December 1985 Lockages	Barges	Tonnage
		St. Louis			
Mississippi	24		1037	6098	6448
	25		1065	6153	6479
	26		2257	14541	14835
	Auxiliary Lock 26		1109	1587	1335
	27		2340	18133	18063
	Auxiliary Lock 27		0	0	0
Kaskaskia	Kaskaskia		658	1575	1125
		Rock Island			
Mississippi	11		589	3059	3469
	12		541	3272	3670
	13		551	3261	3646
	14		746	4086	4404
	Auxiliary Lock 14				
	15		806	4058	4488
	Auxiliary Lock 15		110	91	52
	16		845	4398	4823
	17		772	4594	5009
	18		804	4619	5055
	19		530	4886	5384
	Auxiliary Lock 19				
	20		972	5078	5536
	21		983	5522	5867
	22		976	5689	6135
Illinois	T. J. O'Brien		750	1828	1739
	Lockport		1149	5021	4549
	Brandon		1174	5124	4699
	Dresden Island		1154	5363	5180
	Marseilles		1244	5464	5509
	Starved Rock		1254	5934	5930
	Peoria		435	7995	7767
	La Grange		409	8562	8504
		St. Paul			
Mississippi	1	2	309	492	354
	Auxiliary Lock 1				
	2	2	541	3071	3111
	Auxiliary Lock 2				
	3	2	429	2562	2783
	4		477	2651	2890
	5		432	2571	2812

(Continued)

Table B1 (Continued)

River	Lock	October–December 1985 Months	Lockages	Barges	Tonnage
	St. Paul (Continued)				
Mississippi (Continued)	5A		459	2583	2813
	6		461	2792	3042
	7		487	2798	3037
	8		450	2821	3073
	9		444	2822	3205
	10		524	3054	3418
	Upper St. Anthony Falls	2	230	320	237
	Lower St. Anthony Falls	2	324	503	355
	Huntington				
Kanawha	Winfield 1		2372	3533	2545
	Winfield 2		1822	2859	1598
	Marmet 1		1514	2038	1453
	Marmet 2		1289	1663	910
	London 1		317	344	245
	London 2		736	770	549
Ohio	Belleville		710	7987	7633
	Belleville Auxiliary		90	243	124
	Racine		781	8463	7763
	Racine Auxiliary		87	208	99
	Gallipolis		1565	8476	8548
	Gallipolis Auxiliary				
	Greenup		1201	12247	11042
	Greenup Auxiliary		247	427	280
	Meldahl		1127	12000	11356
	Meldahl Auxiliary	2	2	37	10459
	Willow Island		669	7328	6787
	Willow Island Auxiliary		163	375	185
	Louisville				
Green	1		596	3484	2759
	2		640	2447	1847
Ohio	Markland		1113	11843	11789
	Markland Auxiliary		103	202	140
	McAlpine		1471	13291	13858
	McAlpine Auxiliary				
	Cannelton		1258	13236	13683

(Continued)

Table B1 (Continued)

River	Lock	October–December 1985 Months	Lockages	Barges	Tonnage
	Louisville (Continued)				
Ohio (Continued)	Cannelton Auxiliary	2	126	632	605
	Newburgh		1435	14852	14801
	Newburgh Auxiliary		212	376	269
	Uniontown		1646	18632	17236
	Uniontown Auxiliary		109	165	92
	Smithland		1056	10559	13177
	Smithland Auxiliary	2	974	10552	6142
	52		403	22318	20412
	Auxiliary Lock 52	1	268	1214	1162
	Nashville				
Cumberland	Barkley	2	125	661	336
	Cheatham	2	201	1020	818
	Cordell Hull	2	17	33	24
	Old Hickory	2	59	80	68
Tennessee	Melton Hill	2	2	5	0
	Kentucky	2	1007	5932	4936
	Pickwick	2	477	3612	2836
	Pickwick Auxiliary				
	Wilson	2	288	1314	1166
	Wilson Auxiliary				
	Wheeler	2	182	984	903
	Wheeler Auxiliary	2	75	234	200
	Guntersville	2	204	1213	1033
	Guntersville Auxiliary	2	0	0	0
	Nickajack	2	239	1329	996
	Chickamauga	2	182	404	335
	Watts Bar	2	104	228	209
	Fort Loudoun		66	99	104
	Pittsburgh				
Allegheny	2		617	1294	520
	3		654	1318	535
	4		638	1543	467
	5		387	1277	276
	6		372	1134	233
	7		33	45	9
	8		215	201	161
	9	1	10	0	0

(Continued)

Table B1 (Continued)

River	Lock	October-December 1985 Months	Lockages	Barges	Tonnage
	Pittsburgh (Continued)				
Monongahela	2		937	4817	3135
	Auxiliary Lock 2		245	242	104
	3		1237	5814	3115
	Auxiliary Lock 3		393	251	139
	4		957	4834	2635
	Auxiliary Lock 4		163	111	42
	Maxwell		485	2615	982
	Maxwell Auxiliary	2	263	1548	1261
	7		1355	3377	1805
	8		1196	2866	1547
	Morgantown		175	591	296
	Hildebrand		84	304	157
	Opekiska		43	120	57
Ohio	Emsworth		1082	5441	3735
	Emsworth Auxiliary		415	327	145
	Dashields		1006	5823	3900
	Dashields Auxiliary		389	286	131
	Montgomery		1116	6196	4279
	Montgomery Auxiliary		267	159	65
	New Cumberland		621	5823	4996
	New Cumberland Auxiliary		394	946	448
	Pike Island		730	7104	6275
	Pike Island Auxiliary		346	674	332
	Hannibal		777	7697	6961
	Hannibal Auxiliary		148	262	91

(Continued)

Table B1 (Continued)

River	Lock	Total 1985 Months	Lockages	Barges	Tonnage
		St. Louis			
Mississippi	24		4339	26884	26100
	25		4368	26931	26108
	26		8488	54131	52815
	Auxiliary Lock 26		3572	5153	4492
	27		8775	67293	65137
	Auxiliary Lock 27		0	0	0
Kaskaskia	Kaskaskia		2075	5309	3775
		Rock Island			
Mississippi	11	10	2657	14696	14720
	12	10	2740	16070	16053
	13	10	2723	16070	16049
	14	11	3559	19720	19048
	Auxiliary Lock 14	5	0	0	0
	15	11	3521	19129	19186
	Auxiliary Lock 15	9	459	370	153
	16	11	3798	20895	20708
	17	11	3606	21942	21811
	18	11	3717	22451	22293
	19	11	2194	23627	23242
	Auxiliary Lock 19				
	20		4099	24120	23663
	21		4088	24938	24417
	22		4092	25485	25074
Illinois	T. J. O'Brien		2725	6542	5916
	Lockport		3908	16603	14744
	Brandon		4102	16936	15293
	Dresden Island		3973	18022	17205
	Marseilles		4130	18610	18557
	Starved Rock		4313	20219	19976
	Peoria		2861	27289	26605
	La Grange		2439	28708	28539
		St. Paul			
Mississippi	1	9	1438	2251	1677
	Auxiliary Lock 1	9			
	2	9	2694	14799	13025
	Auxiliary Lock 2	9			
	3	9	2347	12743	22666
	4	10	2360	13183	12070

(Continued)

Table B1 (Continued)

River	Lock	Total 1985 Months	Lockages	Barges	Tonnage
	St. Paul (Continued)				
Mississippi (Continued)	5A	10	2632	12987	11964
	5	10	2289	12943	11945
	6	10	2384	13717	12823
	7	10	2466	13725	12810
	8	10	2307	13940	13161
	9	10	2286	13755	13801
	10	10	2549	14704	14461
	Upper St. Anthony Falls	9	1063	1448	1122
	Lower St. Anthony Falls	9	1404	2259	1683
	Huntington				
Kanawha	Winfield 1		9371	13669	10340
	Winfield 2		6314	9399	5323
	Marmet 1		5693	7619	5491
	Marmet 2		4342	5486	2786
	London 1	10	1043	1064	696
	London 2		2674	2706	1982
Ohio	Belleville		2935	33065	31840
	Belleville Auxiliary		352	1049	535
	Racine		3169	35084	32706
	Racine Auxiliary		364	969	509
	Gallipolis		5808	32318	32218
	Gallipolis Auxiliary	8	569	1143	1055
	Greenup		4439	44481	40498
	Greenup Auxiliary		798	1264	640
	Meldahl		4129	44536	41799
	Meldahl Auxiliary	10	244	664	464
	Willow Island		2834	31133	29215
	Willow Island Auxiliary		628	1689	757
	Louisville				
Green	1		2766	13157	10418
	2		2398	9244	6911
Ohio	Markland		3427	35330	35901
	Markland Auxiliary		1414	7350	7454
	McAlpine		5072	45125	48213
	McAlpine Auxiliary	2	220	1213	1323
	Cannelton		4689	48805	50615

(Continued)

Table B1 (Continued)

River	Lock	Total 1985 Months	Lockages	Barges	Tonnage
	Louisville (Continued)				
Ohio (Continued)	Cannelton Auxiliary	10	282	924	766
	Newburgh		5472	56284	55668
	Newburgh Auxiliary		809	1526	858
	Uniontown		5993	66082	63325
	Uniontown Auxiliary		408	694	413
	Smithland		3702	36877	45050
	Smithland Auxiliary		3607	37842	25129
	52		2041	80737	75218
	Auxiliary Lock 52	7	1382	4164	3900
	Nashville				
Cumberland	Barkley		736	4703	2295
	Cheatham		977	5144	4067
	Cordell Hull		131	234	164
	Old Hickory		358	436	320
Tennessee	Melton Hill		1	5	1
	Kentucky		5449	30693	25622
	Pickwick		2019	15021	11816
	Pickwick Auxiliary	5	1117	6349	5005
	Wilson		1974	9045	7720
	Wilson Auxiliary				
	Wheeler		1527	8326	7030
	Wheeler Auxiliary		171	238	203
	Guntersville		1498	7807	6399
	Guntersville Auxiliary	9	0	0	0
	Nickajack		1580	8115	5994
	Chickamauga		2405	2393	1852
	Watts Bar		1233	1219	1079
	Fort Loudoun		632	591	566
	Pittsburgh				
Allegheny	2		3002	5757	2333
	3		3004	5832	2387
	4		2556	5999	1902
	5	11	1419	4935	1058
	6	11	1401	4572	968
	7	11	137	238	59
	8	9	769	741	585
	9	6	6	0	0

(Continued)

Table B1 (Continued)

River	Lock	Total 1985 Months	Lockages	Barges	Tonnage
	Pittsburgh (Continued)				
Monongahela	2		3867	22378	14333
	Auxiliary Lock 2		1857	2169	991
	3		5606	27715	15022
	Auxiliary Lock 3		2239	2728	1380
	4		4650	24446	13143
	Auxiliary Lock 4		1447	2490	1200
	Maxwell		2428	13413	3918
	Maxwell Auxiliary	11	2027	11736	9354
	7		7788	18786	9831
	8		6679	15838	8379
	Morgantown		778	2762	1388
	Hildebrand		435	1479	779
	Opekiska	11	189	422	209
Ohio	Emsworth		4683	24781	16650
	Emsworth Auxiliary		1952	1445	594
	Dashields		4148	24932	16682
	Dashields Auxiliary		2348	2325	1227
	Montgomery		4704	26852	18769
	Montgomery Auxiliary		1044	611	244
	New Cumberland		2518	24200	20500
	New Cumberland Auxiliary		1565	4178	2273
	Pike Island		2946	29755	26204
	Pike Island Auxiliary		1124	2307	1106
	Hannibal		2819	30919	28684
	Hannibal Auxiliary		423	1026	414

(Continued)

Table B1 (Continued)

River	Lock	April–June 1986 Months	Lockages	Barges	Tonnage
		St. Louis			
Mississippi	24		1412	8822	8791
	25		1421	8799	8774
	26		2360	15438	15939
	Auxiliary Lock 26		1010	1106	769
	27		1829	17339	17520
	Auxiliary Lock 27		669	1093	830
Kaskaskia	Kaskaskia		477	1346	944
		Rock Island			
Mississippi	11	10	861	4557	4816
	12	10	941	5143	5380
	13	10	948	5188	5378
	14	10	1121	6223	6301
	Auxiliary Lock 14	8	0	0	0
	15	10	1253	6269	6439
	Auxiliary Lock 15	10	188	134	60
	16	10	1321	6990	7094
	17	10	1201	7207	7476
	18	10	1211	7437	7644
	19	10	715	7867	7883
	Auxiliary Lock 19				
	20	10	1273	8034	8046
	21		1374	8268	8253
	22		13417	8047	8411
Illinois	T. J. O'Brien		726	2051	1768
	Lockport		1188	5512	4882
	Brandon		1203	5509	4950
	Dresden Island		1204	5828	5527
	Marseilles		1188	5693	5751
	Starved Rock		1212	5984	6034
	Peoria		558	7711	7692
	La Grange		418	7022	7501
		St. Paul			
Mississippi	1	10	569	798	514
	Auxiliary Lock 1	10			
	2	10	802	3922	3751
	Auxiliary Lock 2	10			
	3	10	719	3513	3476
	4	10	729	3707	3603
	5	10	718	3678	3631

(Continued)

Table B1 (Continued)

River	Lock	April–June 1986 Months	Lockages	Barges	Tonnage
	St. Paul (Continued)				
Mississippi (Continued)	5A	10	797	3687	3627
	6	10	758	3990	3958
	7	10	855	3995	3949
	8	10	771	4145	4124
	9	10	757	4127	4450
	10	10	838	4483	4787
	Upper St. Anthony Falls	10	328	347	262
	Lower St. Anthony Falls	10	556	783	518
	Huntington				
Kanawha	Winfield 1		2508	3822	2755
	Winfield 2		2230	3523	2000
	Marmet 1		1944	2386	1713
	Marmet 2		1364	1742	1001
	London 1		712	736	568
	London 2		478	484	307
Ohio	Belleville		741	8826	8575
	Belleville Auxiliary		108	313	176
	Racine		827	9502	8948
	Racine Auxiliary		130	405	219
	Gallipolis		1497	8849	8798
	Gallipolis Auxiliary	9	347	745	737
	Greenup		1044	10825	9950
	Greenup Auxiliary		461	1837	1529
	Meldahl		1098	12476	11783
	Meldahl Auxiliary	11	91	145	94
	Willow Island		741	8533	7948
	Willow Island Auxiliary		202	670	320
	Louisville				
Green	1		751	2768	2200
	2		518	1947	1446
Ohio	Markland		1071	11658	11894
	Markland Auxiliary		127	245	159
	McAlpine		1392	12672	13683
	McAlpine Auxiliary	8	44	101	98
	Cannelton		1262	13518	14052

(Continued)

Table B1 (Continued)

River	Lock	April–June 1986 Months	Lockages	Barges	Tonnage
	Louisville (Continued)				
Ohio (Continued)	Cannelton Auxiliary		151	282	143
	Newburgh		1468	15900	15186
	Newburgh Auxiliary		310	611	415
	Uniontown		1623	17944	17162
	Uniontown Auxiliary		200	301	192
	Smithland		933	9412	11382
	Smithland Auxiliary		1034	10858	7622
	52		693	21985	20382
	Auxiliary Lock 52	10	403	1140	1015
	Nashville				
Cumberland	Barkley		759	4853	3474
	Cheatham		318	1617	1224
	Cordell Hull	8			
	Old Hickory		140	215	163
Tennessee	Melton Hill	11	18	2	0
	Kentucky		1042	6173	5176
	Pickwick		843	6466	5077
	Pickwick Auxiliary				
	Wilson		599	2862	2487
	Wilson Auxiliary				
	Wheeler		493	2733	2277
	Wheeler Auxiliary	9			
	Guntersville		478	2592	1999
	Guntersville Auxiliary		1	0	0
	Nickajack		451	2181	1604
	Chickamauga		736	735	572
	Watts Bar		458	468	374
	Fort Loudoun		160	148	144
	Pittsburgh				
Allegheny	2		756	1524	555
	3		713	1538	560
	4		586	1383	404
	5		384	1155	266
	6		101	158	54
	7		97	157	56
	8	8	8	5	1
	9	8	3	0	0

(Continued)

Table B1 (Continued)

River	Lock	April–June 1986 Months	Lockages	Barges	Tonnage
	Pittsburgh (Continued)				
Monongahela	2		1117	6685	4334
	Auxiliary Lock 2		375	381	160
	3		1657	8244	4710
	Auxiliary Lock 3		617	418	206
	4		1380	7139	4047
	Auxiliary Lock 4		299	361	158
	Maxwell		616	3676	966
	Maxwell Auxiliary		570	3371	2892
	7		2086	5213	2823
	8		1757	4340	2382
	Morgantown		278	880	445
	Hildebrand		116	382	200
	Opekiska		41	118	46
Ohio	Emsworth		1246	7036	4688
	Emsworth Auxiliary		602	447	186
	Dashields		1188	7502	4946
	Dashields Auxiliary		473	439	227
	Montgomery		1556	8317	5517
	Montgomery Auxiliary	10	30	12	8
	New Cumberland		688	7030	5821
	New Cumberland	11	447	1102	558
	Pike Island		776	8383	7370
	Pike Island Auxiliary	11	380	937	448
	Hannibal		717	8213	7944
	Hannibal Auxiliary	11	130	414	208

(Continued)

Table B1 (Continued)

River	Lock	October–December 1986 Months	Lockages	Barges	Tonnage
		St. Louis			
Mississippi	24		1247	7654	7879
	25		1307	7692	7898
	26		2125	14774	14893
	Auxiliary Lock 26		1451	2878	2671
	27		1857	18205	18252
	Auxiliary Lock 27		716	1432	1085
Kaskaskia	Kaskaskia		377	955	723
		Rock Island			
Mississippi	11		456	2550	2983
	12		502	3040	3504
	13		536	3030	3522
	14		812	4323	4762
	Auxiliary Lock 14				
	15		853	4306	4891
	Auxiliary Lock 15		81	91	51
	16		919	4901	5423
	17		903	5227	5818
	18		929	5407	6009
	19		579	6009	6597
	Auxiliary Lock 19				
	20		1136	6338	6849
	21		1199	6992	7279
	22		1180	7201	7530
Illinois	T. J. O'Brien		548	1678	1539
	Lockport		1039	4764	4250
	Brandon		1028	4815	4325
	Dresden Island		982	5134	4860
	Marseilles		1006	5217	5144
	Starved Rock		1102	5639	5549
	Peoria		12	7795	7570
	La Grange		41	8430	8232
		St. Paul			
Mississippi	1		273	452	267
	Auxiliary Lock 1				
	2		401	1901	2015
	Auxiliary Lock 2				
	3		384	1872	2005
	4		401	2022	2146
	5		392	2003	2122

(Continued)

Table B1 (Continued)

River	Lock	October–December 1986 Months	Lockages	Barges	Tonnage
	St. Paul (Continued)				
Mississippi (Continued)	5A		415	2023	2155
	6		453	2317	2467
	7		460	2296	2442
	8		467	2457	2611
	9		457	2404	2764
	10		526	2595	2954
	Upper St. Anthony Falls		201	227	162
	Lower St. Anthony Falls		319	497	306
	Huntington				
Kanawha	Winfield 1		1732	2851	2116
	Winfield 2		2114	3429	1969
	Marmet 1		1584	2301	1544
	Marmet 2		967	1345	717
	London 1		207	230	219
	London 2		798	865	541
Ohio	Belleville		655	7571	7255
	Belleville Auxiliary		73	192	99
	Racine		737	8080	7599
	Racine Auxiliary		139	370	157
	Gallipolis		1518	8688	8579
	Gallipolis Auxiliary		166	236	107
	Greenup		1114	11188	10538
	Greenup Auxiliary		314	366	216
	Meldahl		1099	11725	11007
	Meldahl Auxiliary		49	91	59
	Willow Island		650	7192	6758
	Willow Island Auxiliary		167	477	215
	Louisville				
Green	1		545	2530	2111
	2		467	1779	1321
Ohio	Markland		1064	11107	10964
	Markland Auxiliary		134	265	227
	McAlpine		1413	12340	12942
	McAlpine Auxiliary		9	23	37
	Cannelton		1011	10962	11195

(Continued)

Table B1 (Continued)

River	Lock	October–December 1986 Months	Lockages	Barges	Tonnage
		Louisville (Continued)			
Ohio (Continued)	Cannelton Auxiliary		498	2692	2542
	Newburgh		1488	15695	15183
	Newburgh Auxiliary		281	460	333
	Uniontown		1667	18567	17508
	Uniontown Auxiliary		182	344	196
	Smithland		1020	10551	12220
	Smithland Auxiliary		1010	10729	7421
	52		48	23104	21360
	Auxiliary Lock 52		267	1214	1161
		Nashville			
Cumberland	Barkley		342	1993	1068
	Cheatham		295	1473	1095
	Cordell Huil		27	51	37
	Old Hickory		160	223	176
Tennessee	Melton Hill		0	0	0
	Kentucky		1516	8874	7573
	Pickwick		774	5959	4633
	Pickwick Auxiliary				
	Wilson		532	2458	2206
	Wilson Auxiliary				
	Wheeler		441	2349	2072
	Wheeler Auxiliary		1	0	0
	Guntersville		427	2122	1842
	Guntersville Auxiliary		0	0	0
	Nickajack		440	1880	1515
	Chickamauga		705	688	603
	Watts Bar		418	415	393
	Fort Loudoun		164	139	158
		Pittsburgh			
Allegheny	2		688	1373	535
	3		684	1380	543
	4		653	1683	436
	5		271	636	137
	6		42	39	9
	7		34	32	8
	8		230	214	173
	9		10	0	0

(Continued)

Table B1 (Continued)

River	Lock	October–December 1986 Months	Lockages	Barges	Tonnage
	Pittsburgh (Continued)				
Monongahela	2		819	4864	2953
	Auxiliary Lock 2		400	446	184
	3		1188	5778	3356
	Auxiliary Lock 3		512	364	176
	4		1165	5810	3375
	Auxiliary Lock 4		217	202	69
	Maxwell		556	3088	838
	Maxwell Auxiliary		474	2667	2288
	7		2070	5359	2902
	8		1771	4445	2465
	Morgantown		277	910	459
	Hildebrand		108	445	235
	Opekiska		87	180	87
Ohio	Emsworth		1012	5423	3417
	Emsworth Auxiliary		588	492	204
	Dashields		925	5584	3498
	Dashields Auxiliary		719	842	450
	Montgomery		1304	6695	4337
	Montgomery Auxiliary		115	70	32
	New Cumberland		605	5809	4843
	New Cumberland Auxiliary		504	1419	668
	Pike Island		900	8119	6864
	Pike Island Auxiliary		198	442	184
	Hannibal		644	7275	6844
	Hannibal Auxiliary		119	306	181

(Continued)

Table B1 (Continued)

River	Lock	Total 1986 Months	Lockages	Barges	Tonnage
		St. Louis			
Mississippi	24		4581	28084	28161
	25		4718	28101	28159
	26		8539	56314	56668
	Auxiliary Lock 26		3886	5926	4973
	27		7138	64708	64511
	Auxiliary Lock 27		2413	4757	3850
Kaskaskia	Kaskaskia		2018	5494	3954
		Rock Island			
Mississippi	11	10	2373	12643	13832
	12	10	2588	14356	15528
	13	10	2646	14400	15579
	14	10	3369	18351	18981
	Auxiliary Lock 14	5	0	2	0
	15	10	3550	18117	19355
	Auxiliary Lock 15	10	478	376	205
	16	10	3818	20406	21376
	17	10	3532	21347	22604
	18	10	3595	21989	23114
	19	10	2160	23555	24289
	Auxiliary Lock 19				
	20	10	4036	24235	24854
	21		4389	25726	26038
	22		4443	26448	26896
Illinois	T. J. O'Brien		2261	6910	6214
	Lockport		4221	18770	18758
	Brandon		4255	19020	17095
	Dresden Island		4180	20173	19145
	Marseilles		4257	20320	20210
	Starved Rock		4469	21701	21497
	Peoria		1971	29277	28761
	La Grange		1495	29517	30009
		St. Paul			
Mississippi	1	10	1860	2632	1647
	Auxiliary Lock 1	2	47	76	48
	2	9	2796	12077	11412
	Auxiliary Lock 2	9			
	3	10	2667	11476	11072
	4	10	2664	12098	11628
	5	10	2596	12001	11760

(Continued)

Table B1 (Continued)

River	Lock	Total 1986 Months	Lockages	Barges	Tonnage
		St. Paul (Continued)			
Mississippi (Continued)	5A	10	2841	12065	11795
	6	10	2801	12850	12759
	7	10	2957	12852	12756
	8	10	2702	13361	13336
	9	10	2607	13346	14420
	10	10	2887	14194	15317
	Upper St. Anthony Falls	10	1323	1363	1002
	Lower St. Anthony Falls	10	1903	2749	1766
		Huntington			
Kanawha	Winfield 1		8928	13659	10092
	Winfield 2		8622	13604	7680
	Marmet 1		7051	9145	6434
	Marmet 2		5047	6603	3706
	London 1		1741	1772	1512
	London 2		2978	3100	1948
Ohio	Belleville		2742	32440	31402
	Belleville Auxiliary		331	890	444
	Racine		3096	34774	32756
	Racine Auxiliary		434	1213	571
	Gallipolis	11	5474	31723	31425
	Gallipolis Auxiliary	9	2087	5327	5335
	Greenup		4515	46098	42372
	Greenup Auxiliary		1296	2921	2100
	Meldahl		4368	48542	45741
	Meldahl Auxiliary	11	293	529	343
	Willow Island		2712	30891	29121
	Willow Island Auxiliary		677	1900	876
		Louisville			
Green	1		2443	10570	8561
	2		1947	7461	5565
Ohio	Markland		4315	45934	45701
	Markland Auxiliary		504	922	648
	McAlpine		5621	50465	53445
	McAlpine Auxiliary	7	58	136	145
	Cannelton	11	4076	43731	44929

(Continued)

Table B1 (Continued)

River	Lock	Total 1986 Months	Lockages	Barges	Tonnage
	Louisville (Continued)				
Ohio (Continued)	Cannelton Auxiliary		2213	11968	11902
	Newburgh		5753	61773	59336
	Newburgh Auxiliary		1166	2115	1471
	Uniontown		6490	72192	68167
	Uniontown Auxiliary		707	1118	673
	Smithland		3849	39527	47432
	Smithland Auxiliary		3999	42406	28238
	52		2129	86938	79713
	Auxiliary Lock 52	7	1467	4829	4641
	Nashville				
Cumberland	Barkley		2834	18079	12805
	Cheatham		1146	5762	4396
	Cordell Hull	2	6	8	6
	Old Hickory		564	792	619
Tennessee	Melton Hill	11	7	6	0
	Kentucky		4267	25315	21109
	Pickwick		3216	24781	19085
	Pickwick Auxiliary				
	Wilson		2190	10535	8964
	Wilson Auxiliary				
	Wheeler		1805	10088	8495
	Wheeler Auxiliary	5	2	0	0
	Guntersville		1747	9208	7236
	Guntersville Auxiliary		2	2	0
	Nickajack		1723	8088	6095
	Chickamauga		2675	2653	2146
	Watts Bar		1555	1611	1356
	Fort Loudoun		575	534	531
	Pittsburgh				
Allegheny	2		2772	5405	2071
	3		2685	5446	2106
	4		2243	5400	1559
	5		1040	2830	645
	6		216	305	106
	7		198	280	106
	8	8	541	531	421
	9	6	11	0	0

(Continued)

Table B1 (Continued)

River	Lock	Total 1986 Months	Lockages	Barges	Tonnage
	Pittsburgh (Continued)				
Monongahela	2		3825	23327	14891
	Auxiliary Lock 2		1800	2167	998
	3		6026	29069	16626
	Auxiliary Lock 3		2348	1758	887
	4		5351	27297	15690
	Auxiliary Lock 4		967	886	337
	Maxwell		2389	13679	4253
	Maxwell Auxiliary		2282	13143	10474
	7		8704	22103	11974
	8		7477	18524	10224
	Morgantown		1110	3800	1945
	Hildebrand		492	1889	1032
	Opekiska		259	660	320
Ohio	Emsworth		4650	25599	16954
	Emsworth Auxiliary		2203	1694	692
	Dashields		4285	26951	17749
	Dashields Auxiliary		1892	1735	872
	Montgomery		4758	26050	17587
	Montgomery Auxiliary	10	2519	3856	2508
	New Cumberland		2849	26777	22395
	New Cumberland Auxiliary	11	1439	3715	1820
	Pike Island		3445	33130	28780
	Pike Island Auxiliary	11	953	2039	956
	Hannibal		2739	31245	29721
	Hannibal Auxiliary	11	404	1126	617

(Continued)

Table B1 (Continued)

River	Lock	April–June 1987 Months	Lockages	Barges	Tonnage
		St. Louis			
Mississippi	24		1827	12556	10924
	25		1850	12551	10935
	26		2593	18836	17604
	Auxiliary Lock 26		1831	3999	3553
	27		2030	22160	20774
	Auxiliary Lock 27		1013	2535	2221
Kaskaskia	Kaskaskia		394	942	704
		Rock Island			
Mississippi	11	10	898	5002	4850
	12	11	1211	6585	6174
	13	11	1244	6619	6244
	14		1546	8904	7919
	Auxiliary Lock 14	8	0	0	0
	15		1572	8736	7969
	Auxiliary Lock 15	10	330	262	138
	16		1677	9809	8850
	17		1655	10641	9625
	18		1682	10978	9835
	19		953	11724	10326
	Auxiliary Lock 19				
	20	11	1858	11699	10207
	21		1778	11907	10432
	22		1770	12085	10584
Illinois	T. J. O'Brien		702	2153	1965
	Lockport		1100	4986	4658
	Brandon		1146	5106	4839
	Dresden Island		1140	5472	5573
	Marseilles		1223	5548	5953
	Starved Rock		1313	6160	6603
	Peoria		981	8716	8981
	La Grange		1006	9635	10070
		St. Paul			
Mississippi	1	10	452	699	462
	Auxiliary Lock 1	7			
	2	10	701	3794	3365
	Auxiliary Lock 2	10			
	3	10	675	3726	3310
	4	10	678	3925	3475
	5	10	686	3845	3446

(Continued)

Table B1 (Continued)

River	Lock	Months	April–June 1987 Lockages	Barges	Tonnage
		St. Paul (Continued)			
Mississippi (Continued)	5A	10	679	3877	3495
	6	10	697	4248	3878
	7	10	722	4236	3814
	8	10	697	4320	3954
	9	10	700	4249	4293
	10	10	858	5026	4825
	Upper St. Anthony Falls	11	276	373	275
	Lower St. Anthony Falls	11	413	696	468
		Huntington			
Kanawha	Winfield 1		2426	3591	2847
	Winfield 2		2099	3224	1799
	Marmet 1		1506	2062	1402
	Marmet 2		1439	1931	1173
	London 1		308	322	202
	London 2		988	1076	733
Ohio	Belleville		720	8587	8173
	Belleville Auxiliary		130	312	171
	Racine		674	7667	7256
	Racine Auxilialry		377	1857	1475
	Gallipolis		1607	9547	9144
	Gallipolis Auxiliary		192	312	143
	Greenup		1313	12166	11496
	Greenup Auxiliary	11	135	158	83
	Meldahl		1087	12154	11798
	Meldahl Auxiliary		90	199	126
	Willow Island		709	8171	7601
	Willow Island Auxiliary		193	578	248
		Louisville			
Green	1		612	2907	2279
	2		486	1848	1376
Ohio	Markland		1140	11240	11529
	Markland Auxiliary		50	82	66
	McAlpine		1178	10396	11555
	McAlpine Auxiliary	8	263	1440	1596
	Cannelton		1186	12423	13240

(Continued)

Table B1 (Continued)

River	Lock	April–June 1987 Months	Lockages	Barges	Tonnage
	Louisville (Continued)				
Ohio (Continued)	Cannelton Auxiliary		144	379	311
	Newburgh		1434	14973	14383
	Newburgh Auxiliary		400	736	539
	Uniontown		1604	17351	16955
	Uniontown Auxiliary		209	248	154
	Smithland		1024	10074	12354
	Smithland Auxiliary		1007	10454	6771
	52		684	21946	20238
	Auxiliary Lock 52	9	530	1528	1404
	Nashville				
Cumberland	Barkley		428	2683	1651
	Cheatham		331	1841	1401
	Cordell Hull				
	Old Hickory		158	253	186
Tennessee	Melton Hill	9			
	Kentucky		1480	8845	7 8
	Pickwick		196	1724	1833
	Pickwick Auxiliary	10	676	3974	2598
	Wilson		538	2403	2017
	Wilson Auxiliary				
	Wheeler		426	2291	1951
	Wheeler Auxiliary	11	4	0	0
	Guntersville		354	1791	1480
	Guntersville Auxiliary	10	0	0	0
	Nickajack		405	1687	1349
	Chickamauga		1153	1150	921
	Watts Bar		505	511	494
	Fort Loudoun		189	180	162
	Pittsburgh				
Allegheny	2		58	1497	582
	3		320	1513	594
	4		202	1131	369
	5		160	952	218
	6		4	274	75
	7		3	255	73
	8	10	105	12	0
	9	8	79	0	0

(Continued)

Table B1 (Concluded)

River	Lock	April–June 1987 Months	Lockages	Barges	Tonnage
	Pittsburgh (Continued)				
Monongahela	2		1008	6237	4007
	Auxiliary Lock 2		201	409	169
	3		1654	7916	4547
	Auxiliary Lock 3		539	497	213
	4		1453	7184	4135
	Auxiliary Lock 4		81	266	119
	Maxwell		487	3622	1004
	Maxwell Auxiliary		395	3383	2892
	7		2248	5430	3053
	8		1975	4557	2636
	Morgantown		323	1361	737
	Hildebrand		148	809	449
	Opekiska		24	275	135
Ohio	Emsworth		1246	6915	4557
	Emsworth Auxiliary		148	401	179
	Dashields		1183	7537	4928
	Dashields Auxiliary		101	249	129
	Montgomery		1374	7972	5273
	Montgomery Auxiliary		81	32	17
	New Cumberland		690	6898	5678
	New Cumberland Auxiliary		388	1389	619
	Pike Island		712	7762	6841
	Pike Island Auxiliary		349	1323	707
	Hannibal		668	7654	7255
	Hannibal Auxiliary		131	824	668

APPENDIX C: DATA BASE EDIT PROGRAM

```
      CHARACTER LINE(132),DUMMI,UP*9,DN*9
      OPEN(UNIT=15,FILE='DATA1')
      OPEN(UNIT=16,FILE='DATA2')
C
C     SETR FLAGS & CONSTAINTS
C
      IEND=0
      IUFLAG=0
      UP='UPBOUND'
      DN='DOWNBOUND'
C
C     READ PAST INITIAL HEADINGS
C
      DO 5 I=1,8
    5 READ(15,'(1A1)')DUMMI
C
C     READ AND PRINT FILES
C
      DO 10 I=1,5
10    READ(15,'(132A1)')(LINE(J),J=1,90)
C     WRITE(16,'(132A1)')(LINE(J),J=1,90)
C     READ UP OR DOWNBOUND
      READ(15,'(132A1)')(LINE(J),J=1,90)
      IF(LINE(55).EQ.'U')THEN
         IUFLAG=1
      ELSE
         IUFLAG=0
      END IF
      DO 15,I=1,6
 15   READ(15,'(132A1)')(LINE(J),J=1,90)
C  15 WRITE(16,'(132A1)')(LINE(J),J=1,90)
C
C     READ, TEST, AND PRINT INFO
C
   20 READ(15,'(132A1)',END=21)(LINE(I),I=1,120)
      GO TO 22
   21 IEND=1
      GO TO 28
C
C     IF LINE(1)=1 --> BLOCK END, THEN READ PAST NEXT SET OF HEADINGS
C     AND PICK UP UPBOUND OR DOWNBOUND INFO
C
   22 IF(LINE(1).EQ.'1') THEN
         DO 25 K=1,5
   25    READ(15,'(132A1)')(LINE(I),I=1,120)
         IF(LINE(55).EQ.'U') THEN
            IUFLAG=1
            ELSE
              IUFLAG=0
            END IF
        DO 27,I=1,6
   27   READ(15,'(1A1)')DUMMI
      END IF
   28   IF (LINE(53).EQ.'/')THEN
          IF(IUFLAG.EQ.0)THEN
            WRITE(16,'(132A1,4X,A9)')(LINE(I),I=1,120),DN
          ELSE
                WRITE(16,'(132A1,4X,A9)')(LINE(I),I=1,120),UP
         END IF
      END IF
      IF(IEND.NE.1) GO TO 20
  300 PRINT*,'EOF FOUND'
      STOP
      END
```

APPENDIX D: PMS LOCK PROCESSING CHARTS

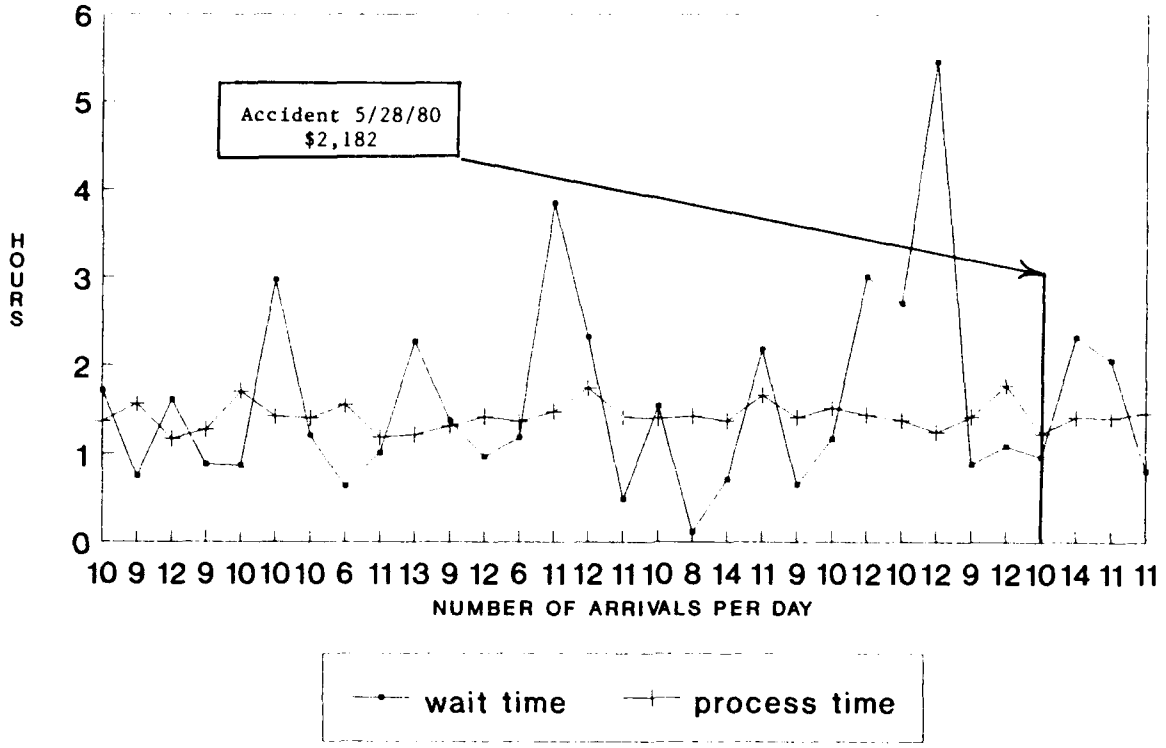


Figure D1. Variation in average daily lock delays, Lock 24, May 1980

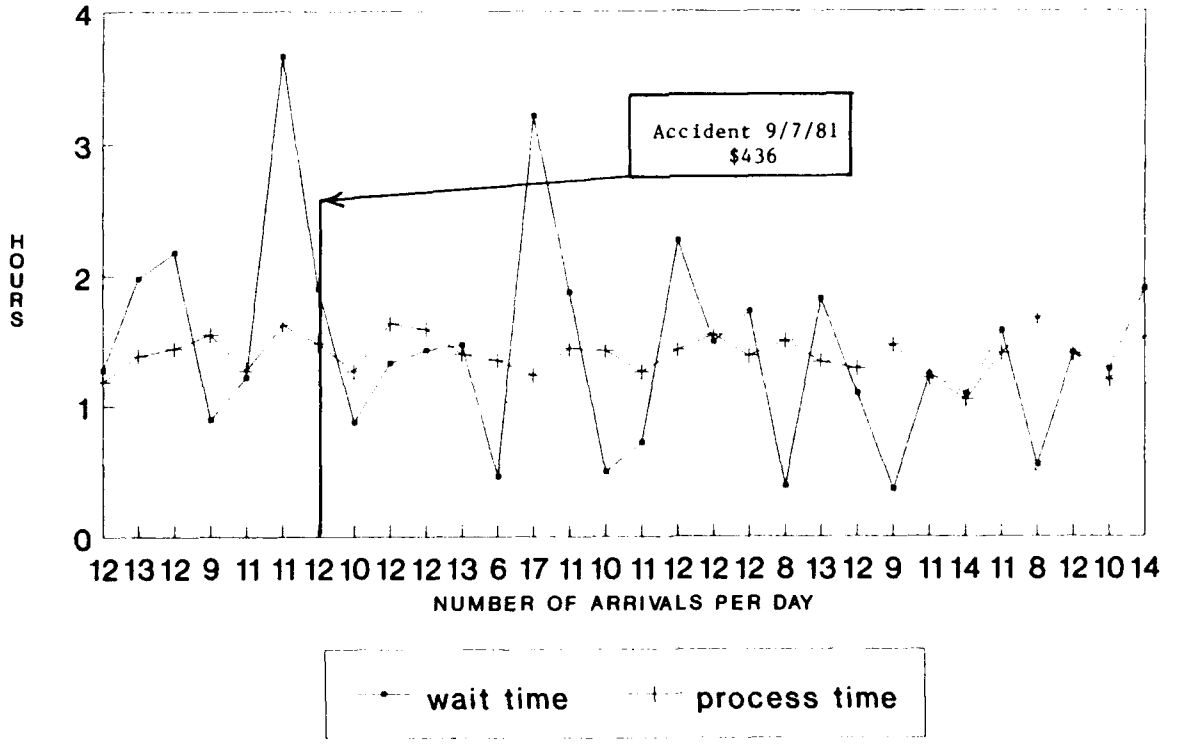


Figure D2. Variation in average daily lock delays, Lock 24, September 1981

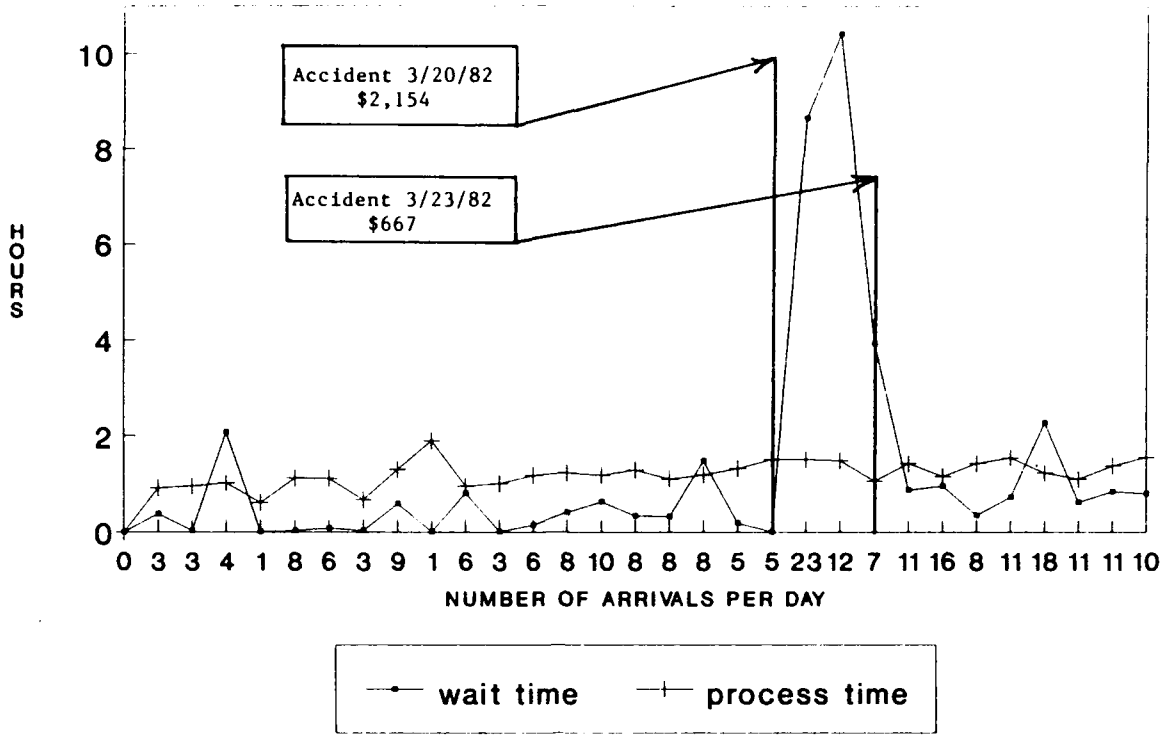


Figure D3. Variation in average daily lock delays, Lock 24, March 1982

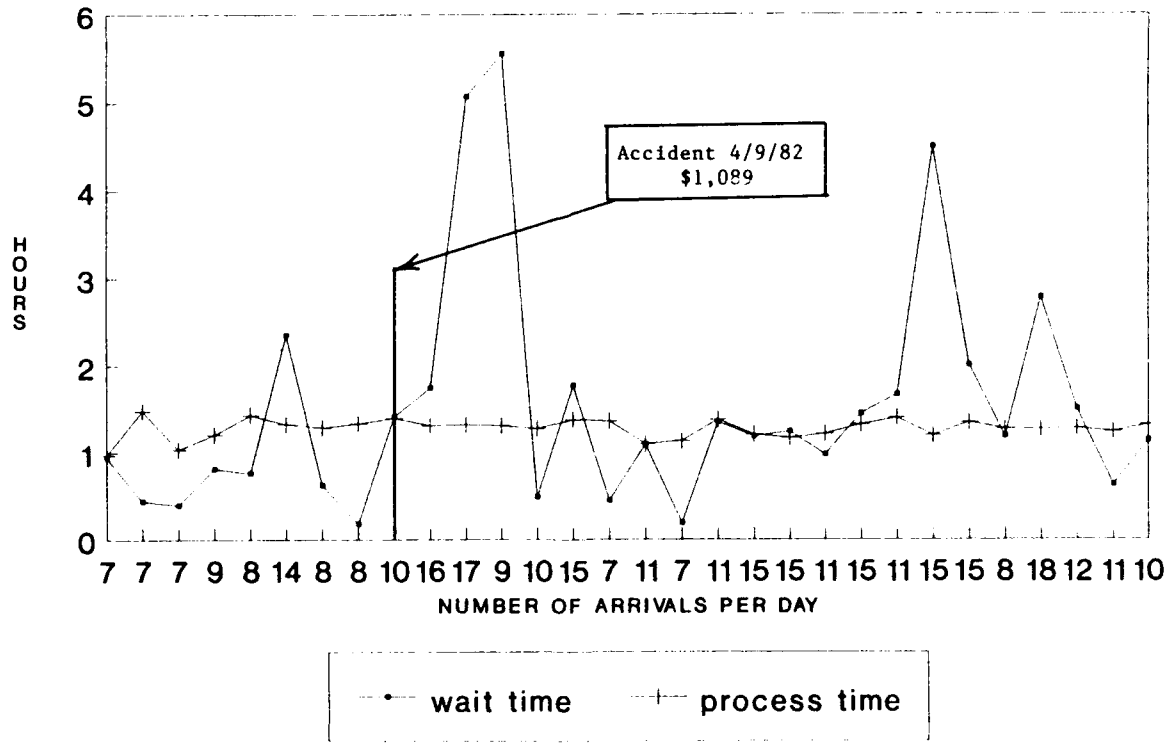


Figure D4. Variation in average daily lock delays, Lock 24, April 1982

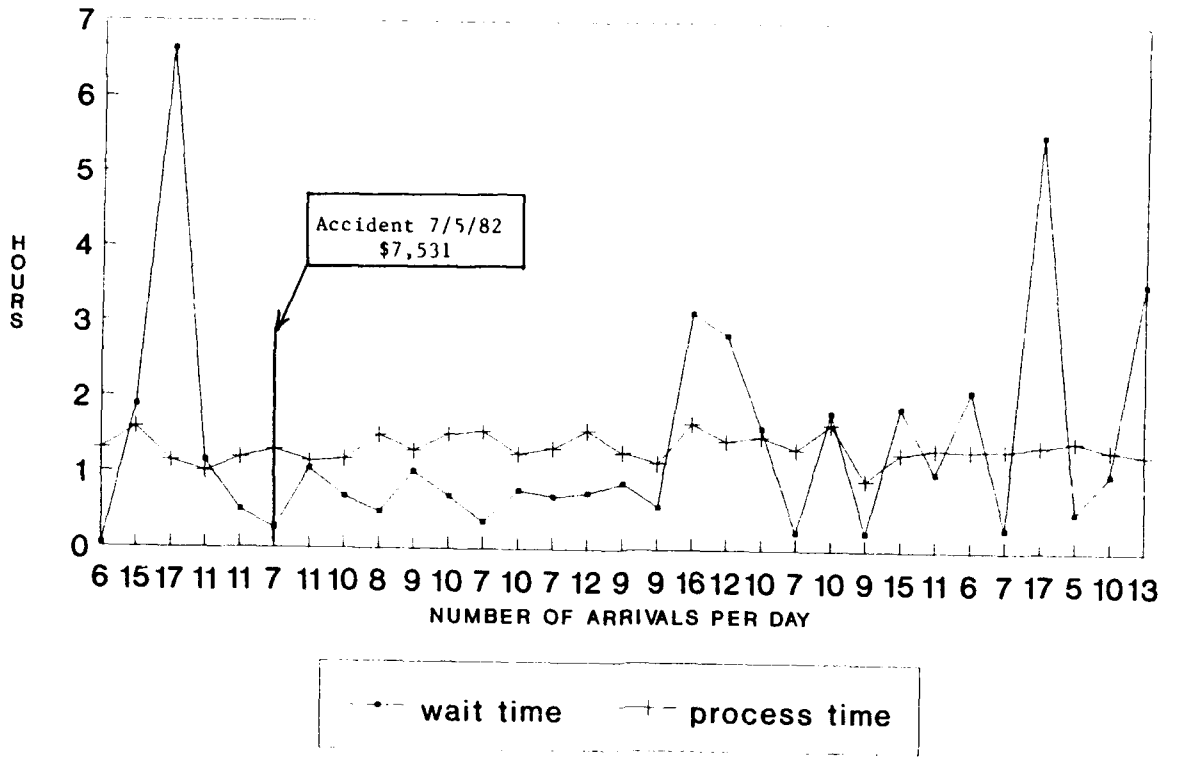


Figure D5. Variation in average daily lock delays, Lock 24, July 1982

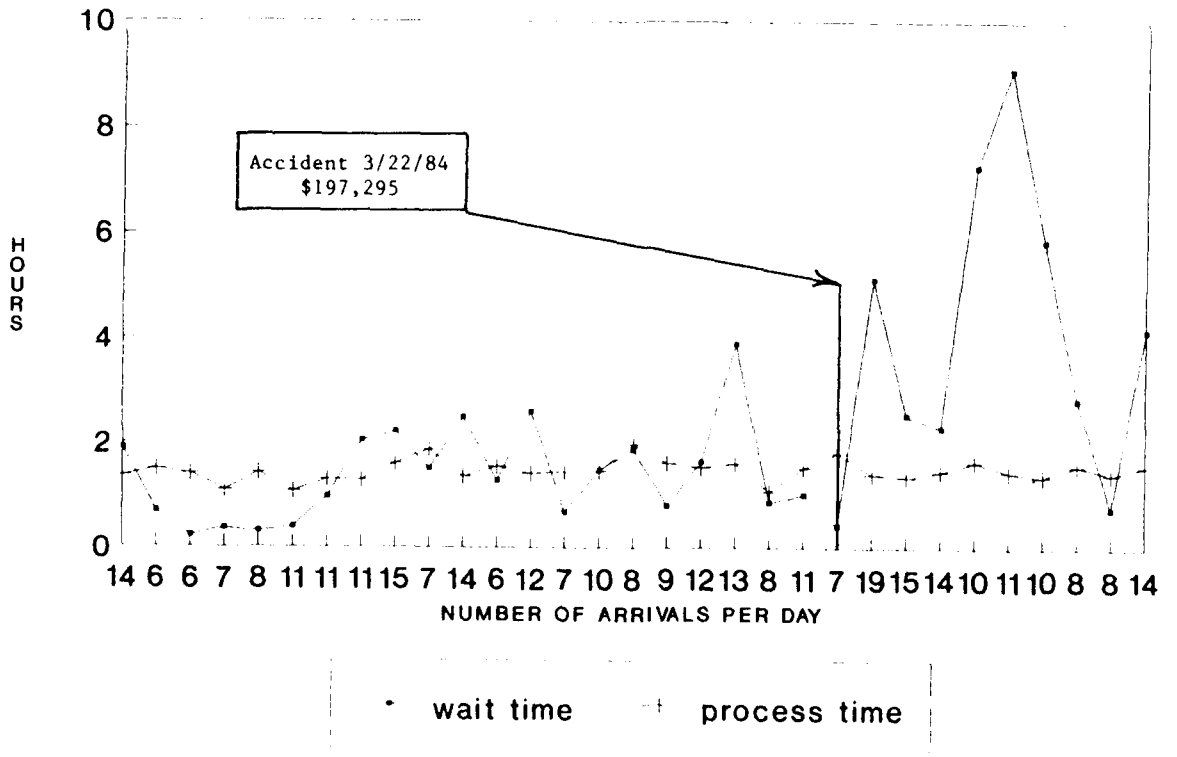


Figure D6. Variation in average daily lock delays, Lock 24, March 1984

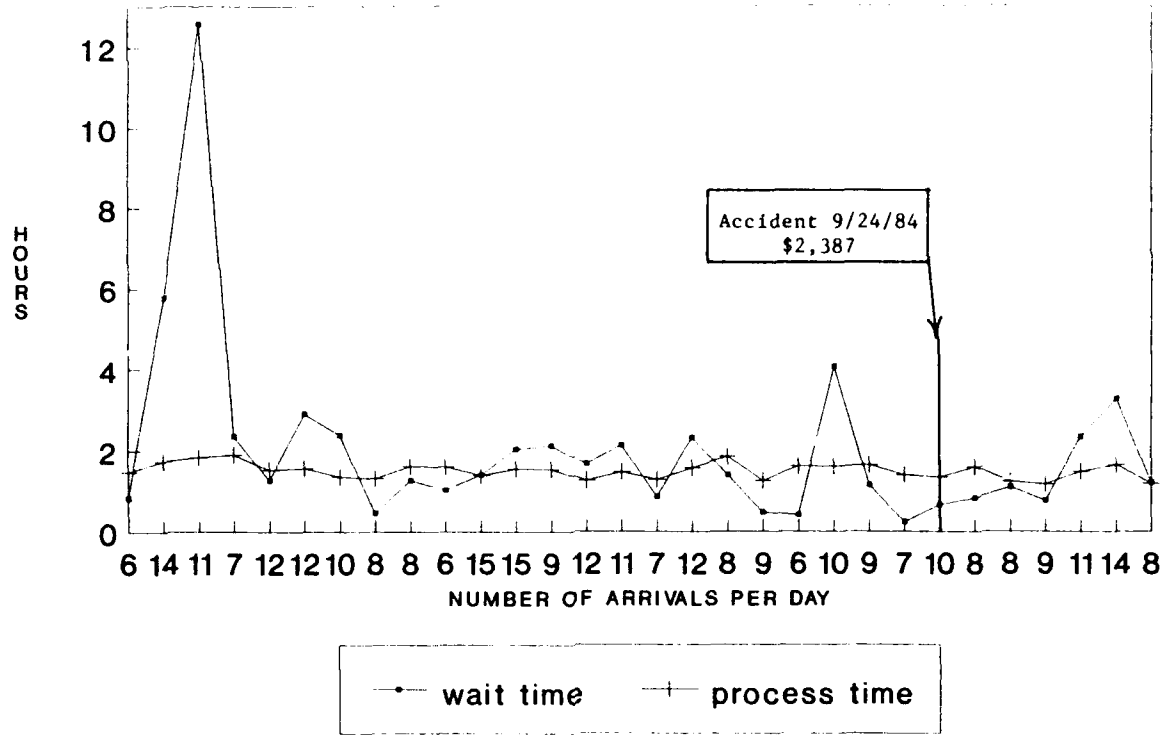


Figure D7. Variation in average daily lock delays, Lock 24, September 1984

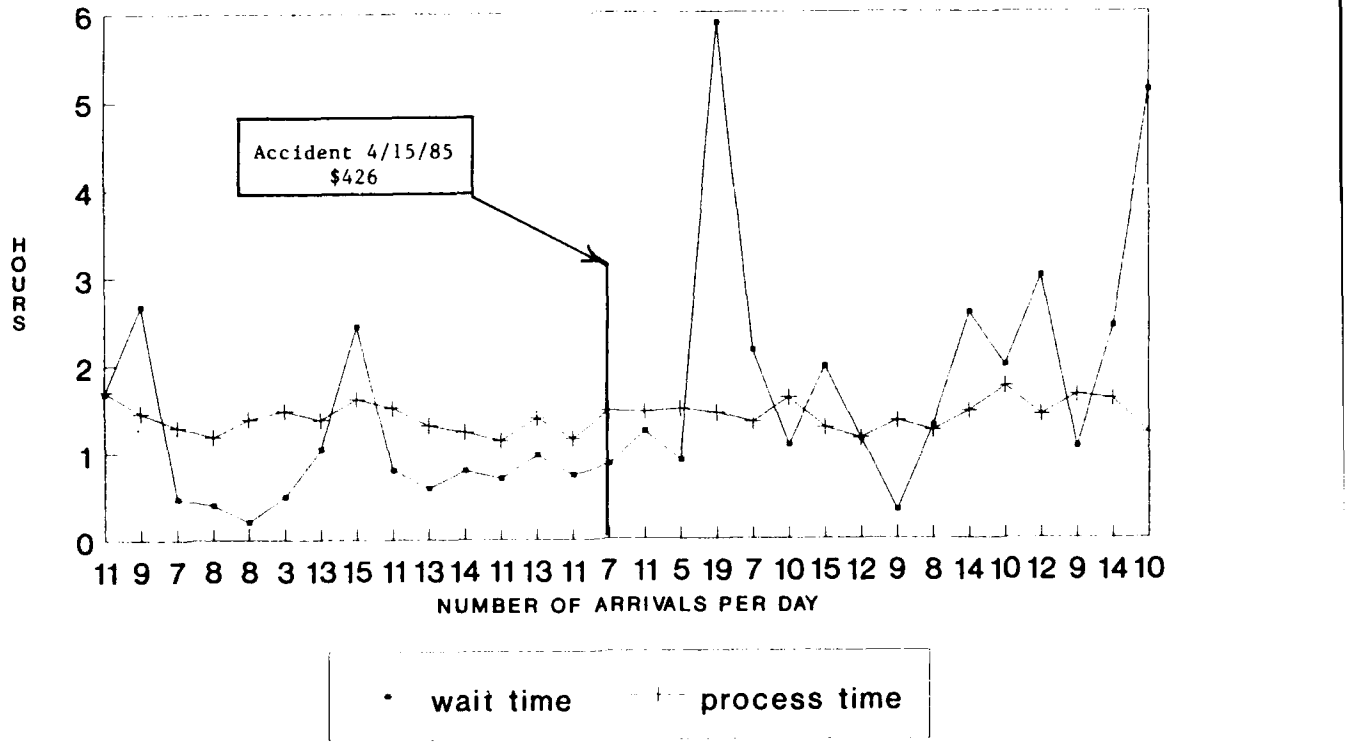


Figure D8. Variation in average daily lock delays, Lock 24, April 1985

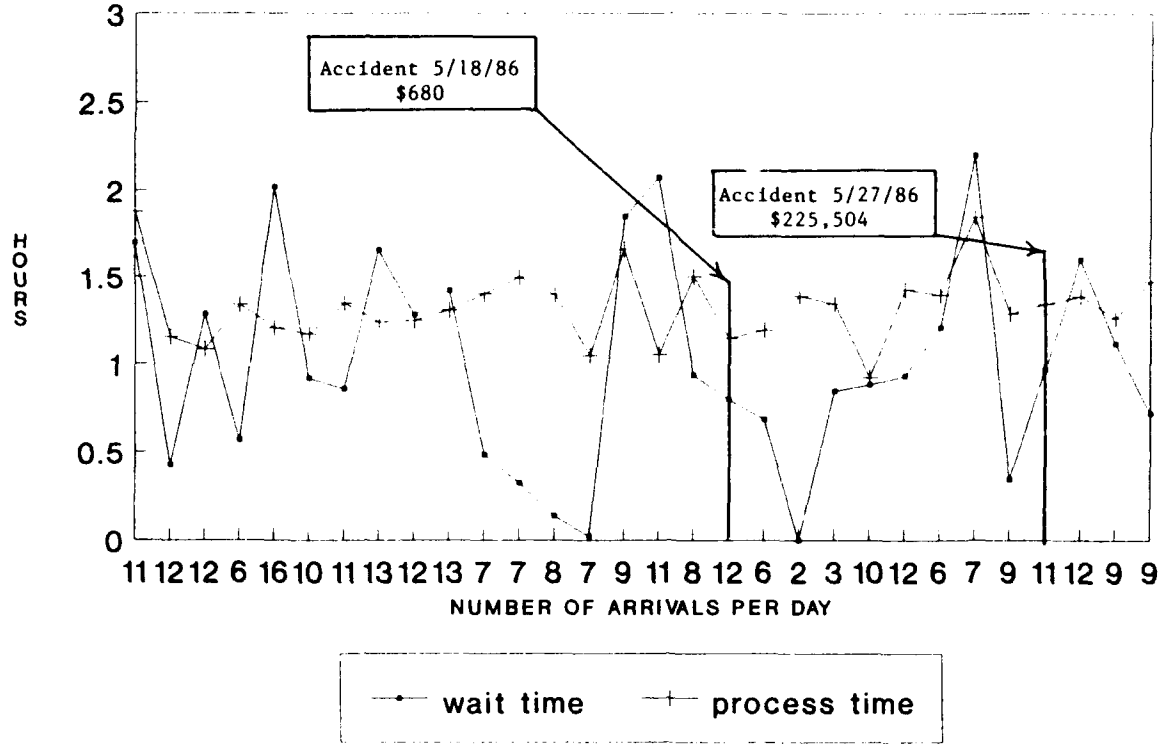


Figure D9. Variation in average daily lock delays, Lock 24, May 1986

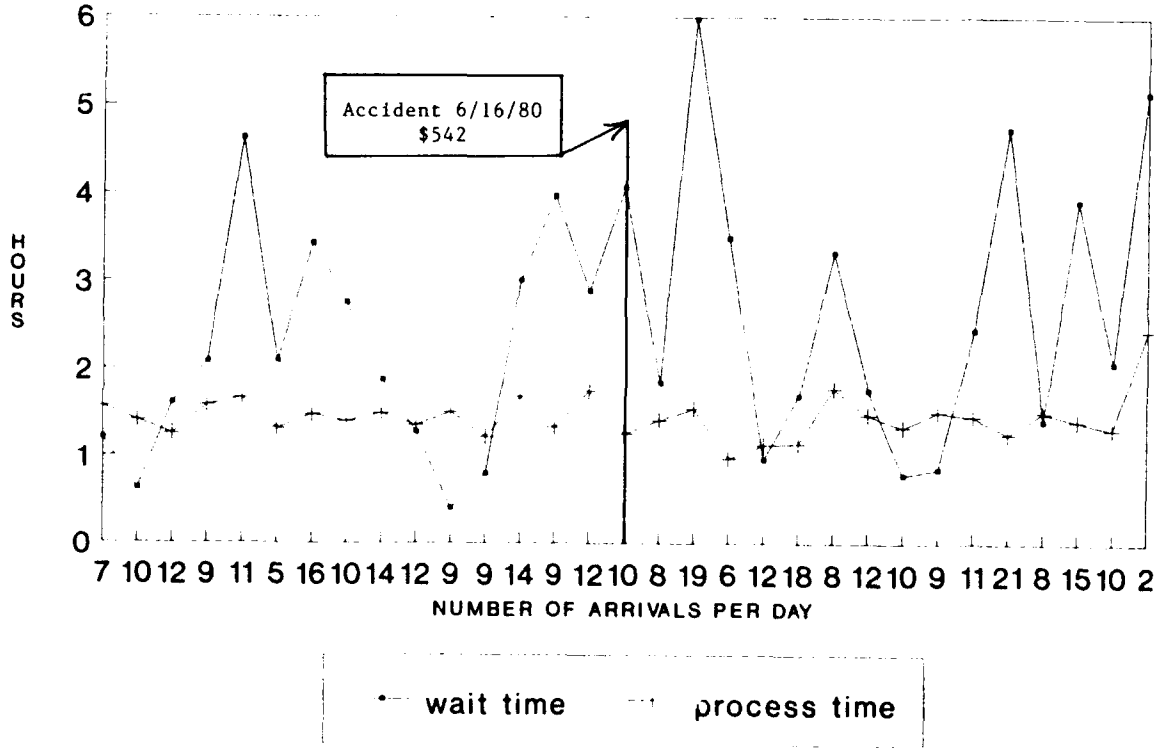


Figure D10. Variation in average daily lock delays, Lock 25, June 1980

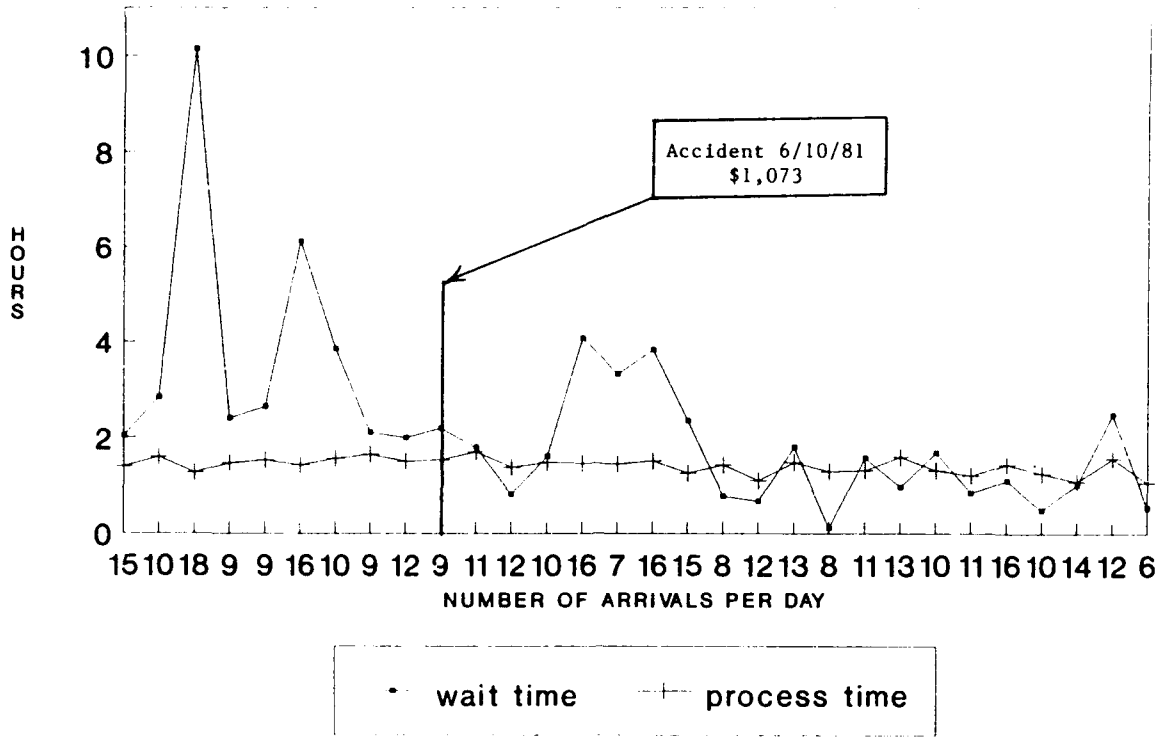


Figure D11. Variation in average daily lock delays, Lock 25, June 1981

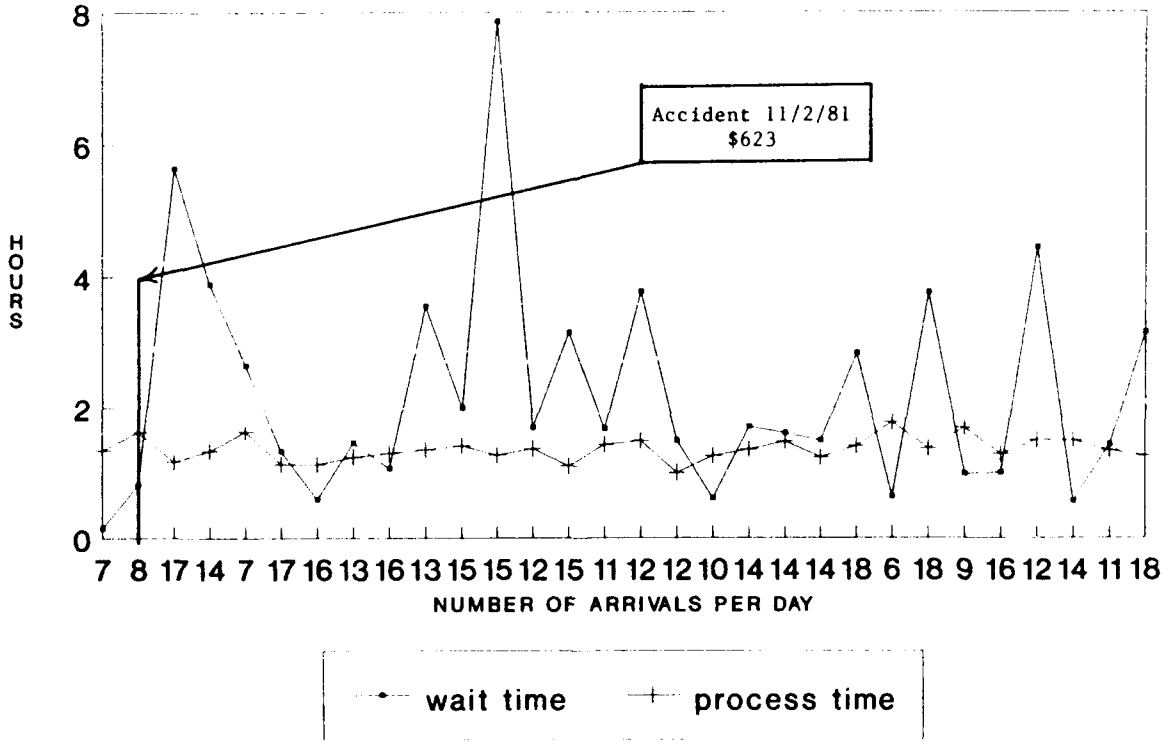


Figure D12. Variation in average daily lock delays, Lock 25, November 1981

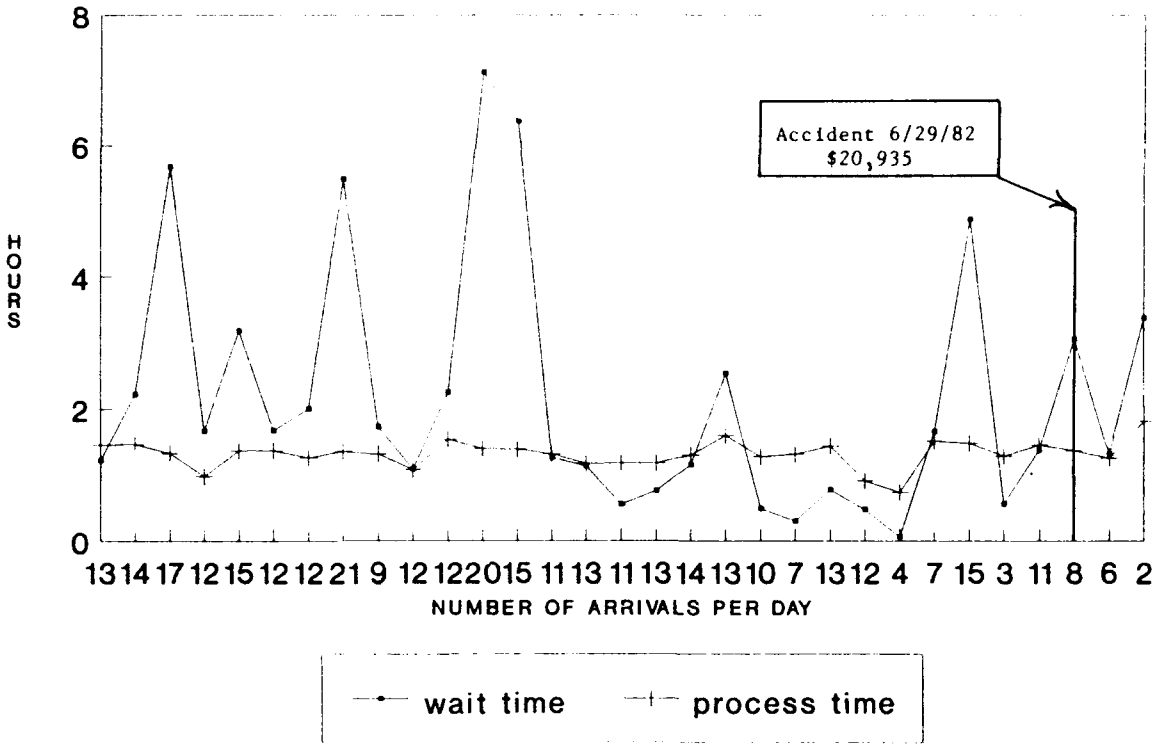


Figure D13. Variation in average daily lock delays, Lock 25, June 1982

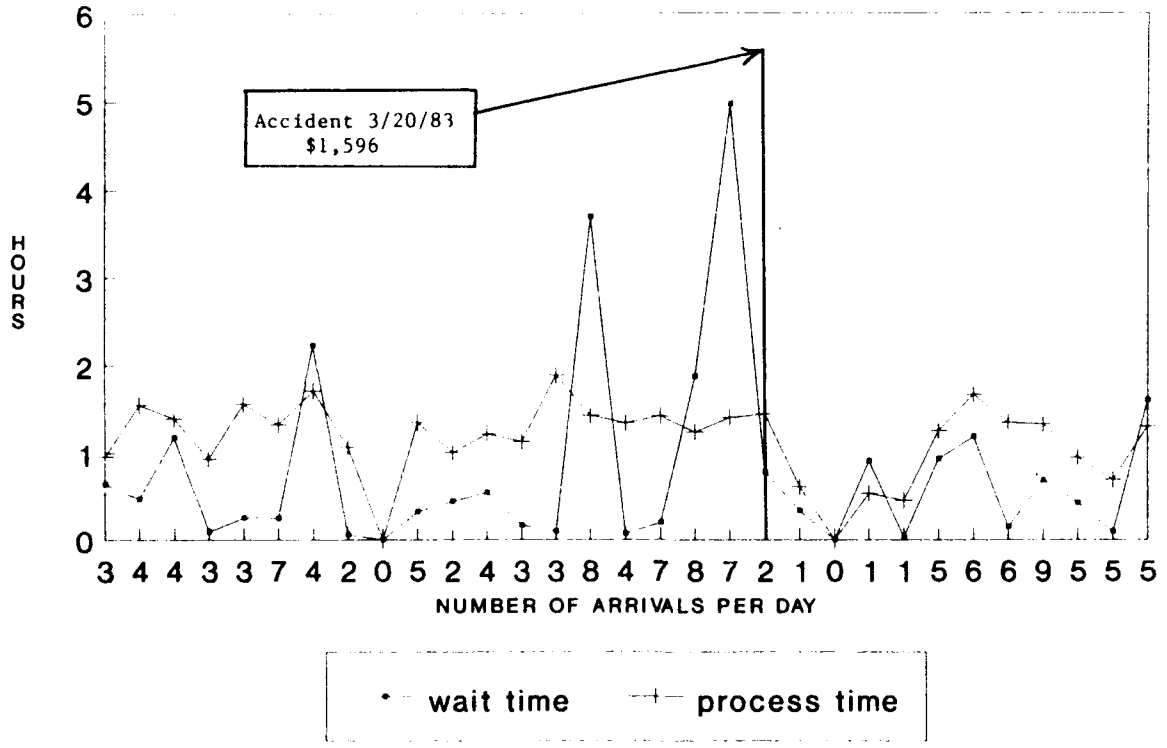


Figure D14. Variation in average daily lock delays, Lock 25, March 1983

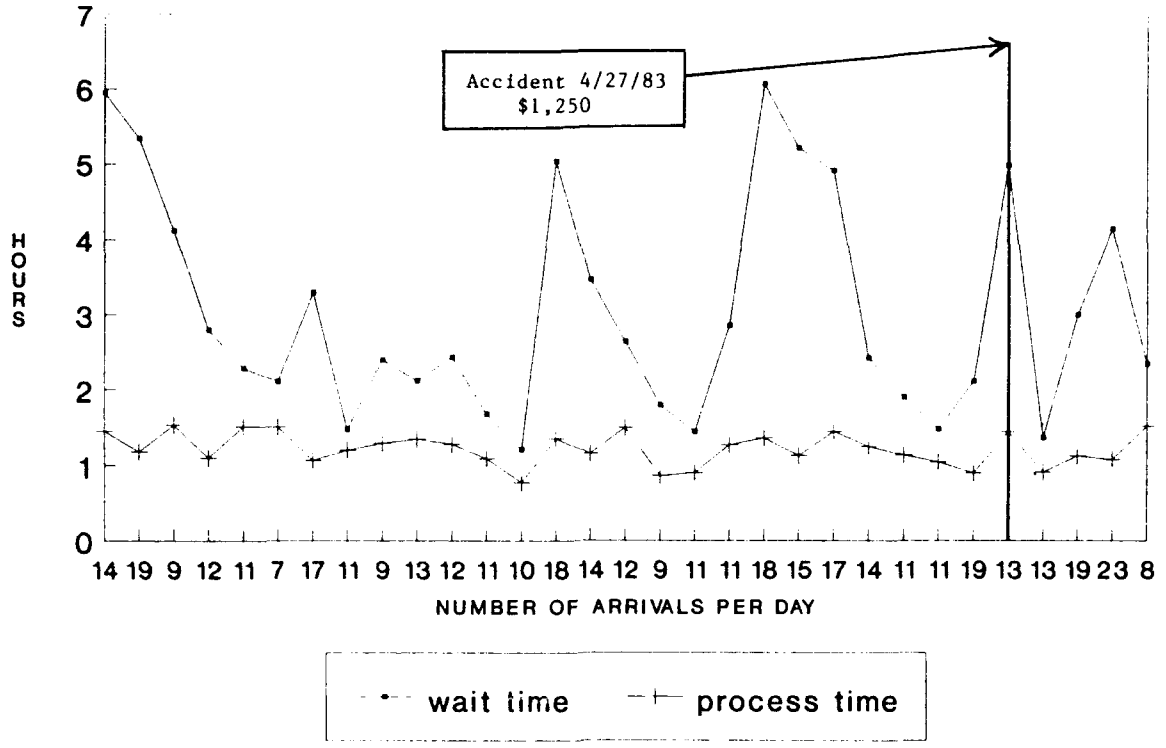


Figure D15. Variation in average daily lock delays, Lock 25, April 1983

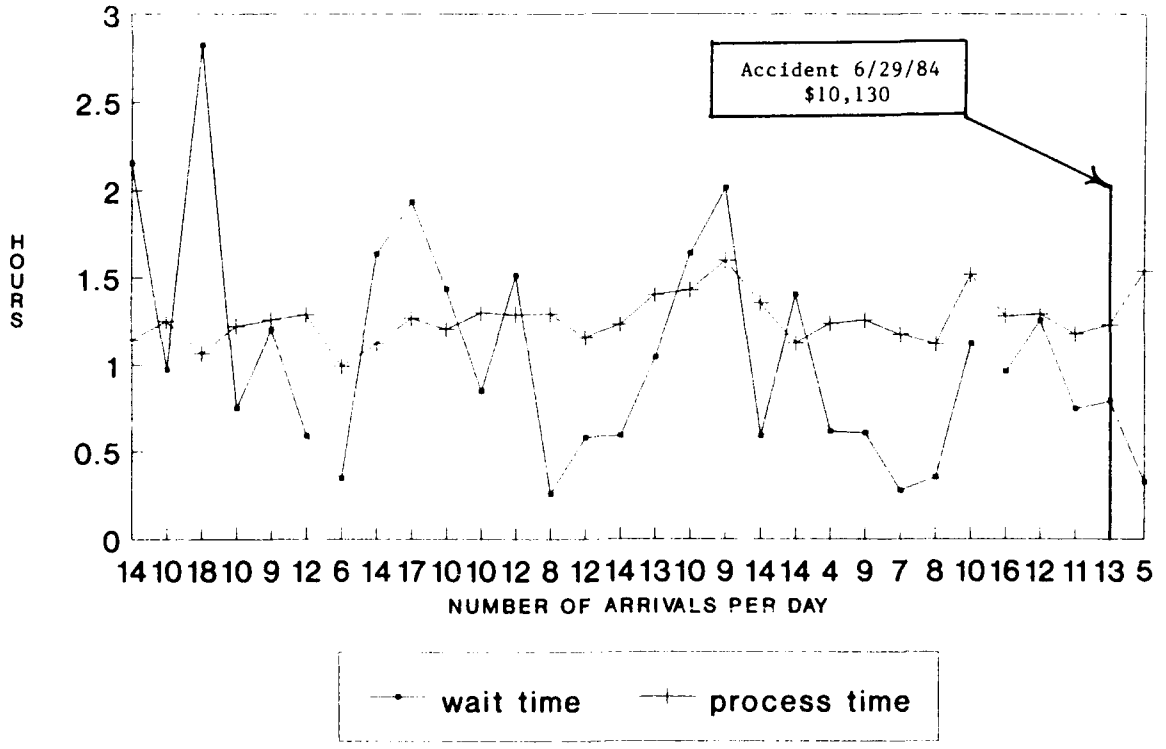


Figure D16. Variation in average daily lock delays, Lock 25, June 1984

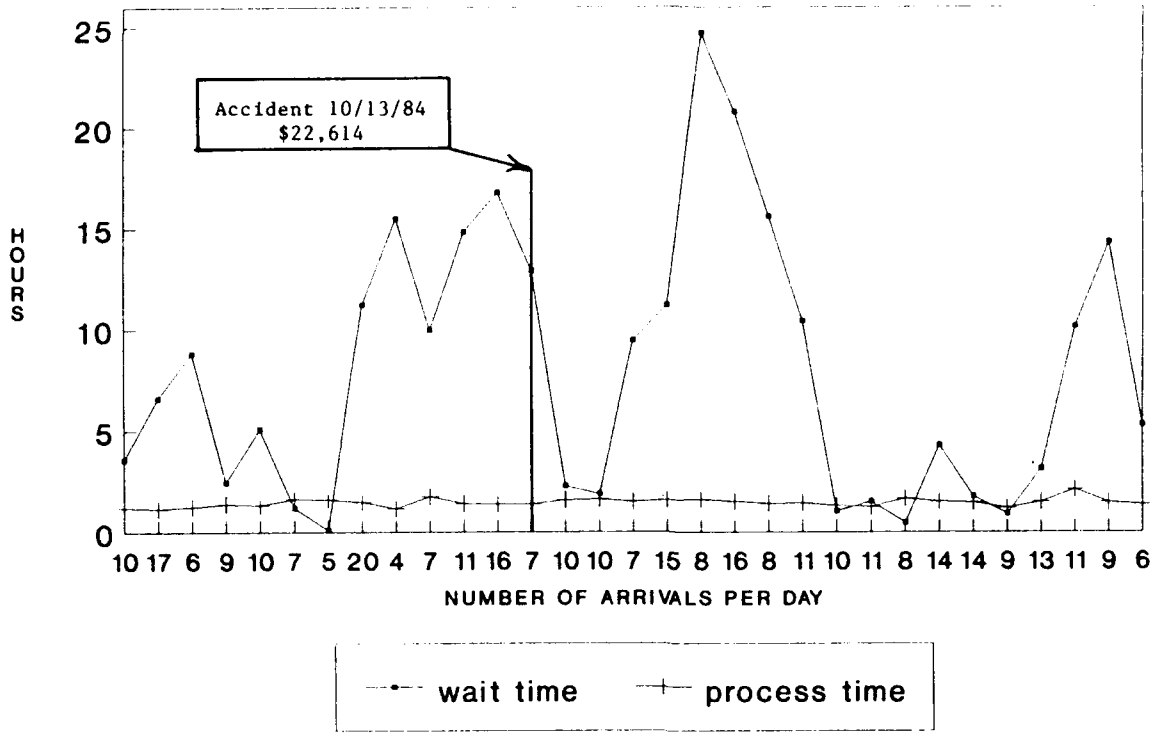


Figure D17. Variation in average daily lock delays, Lock 25, October 1984

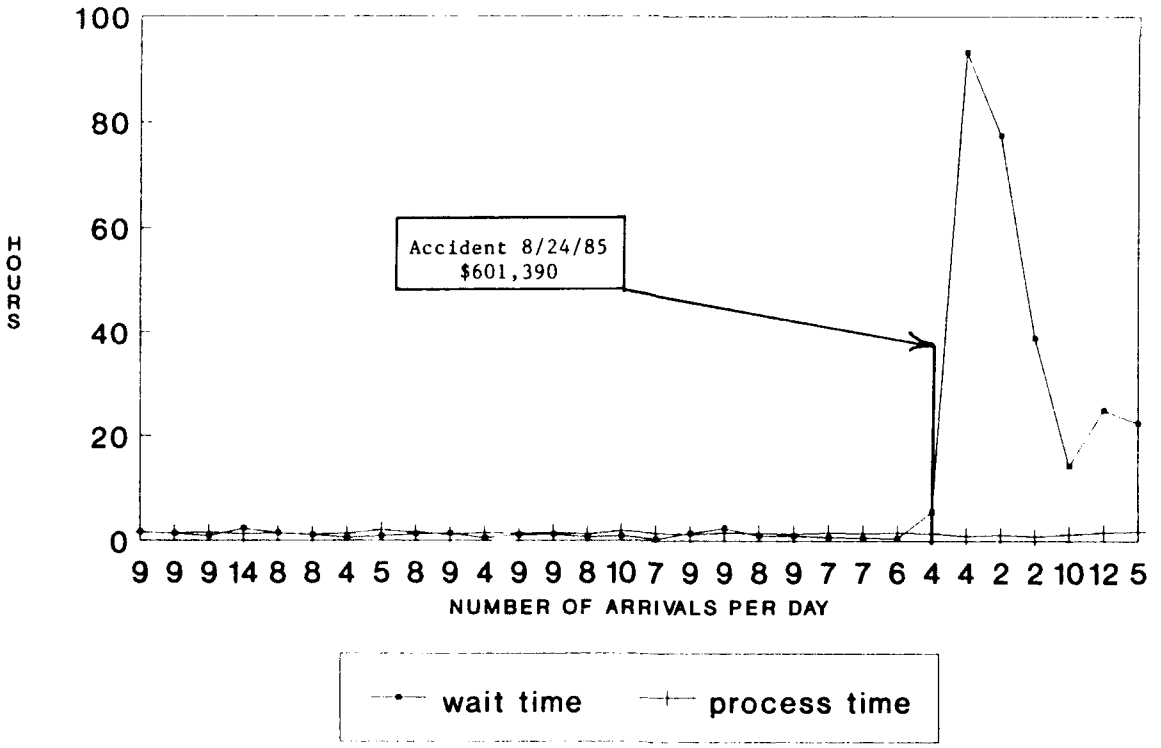


Figure D18. Variation in average daily lock delays, Lock 25, August 1985